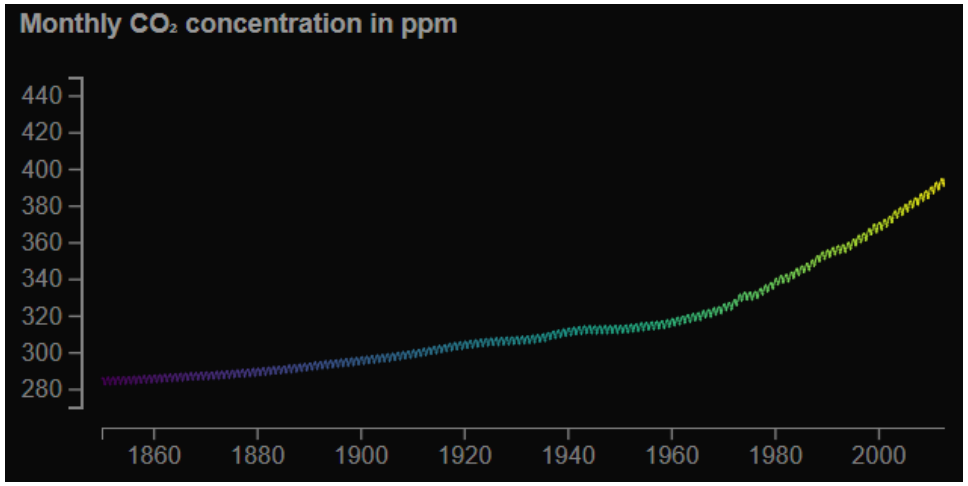
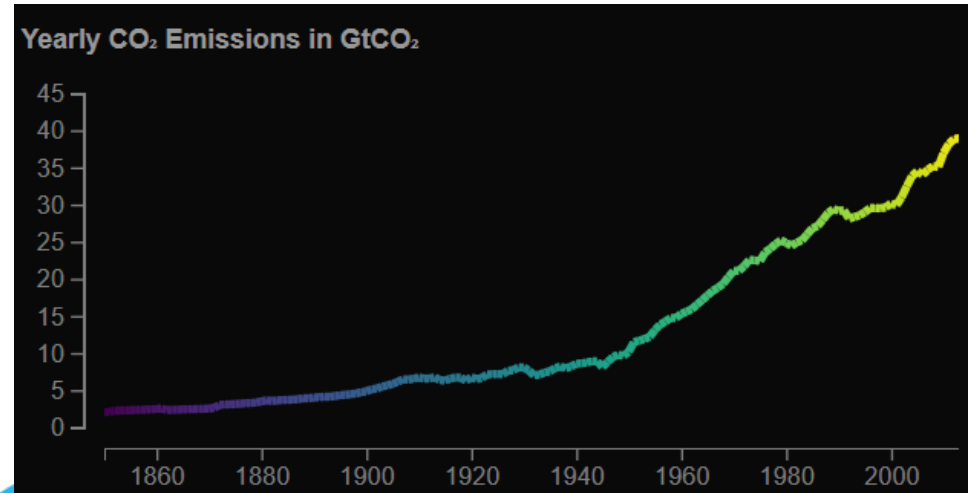
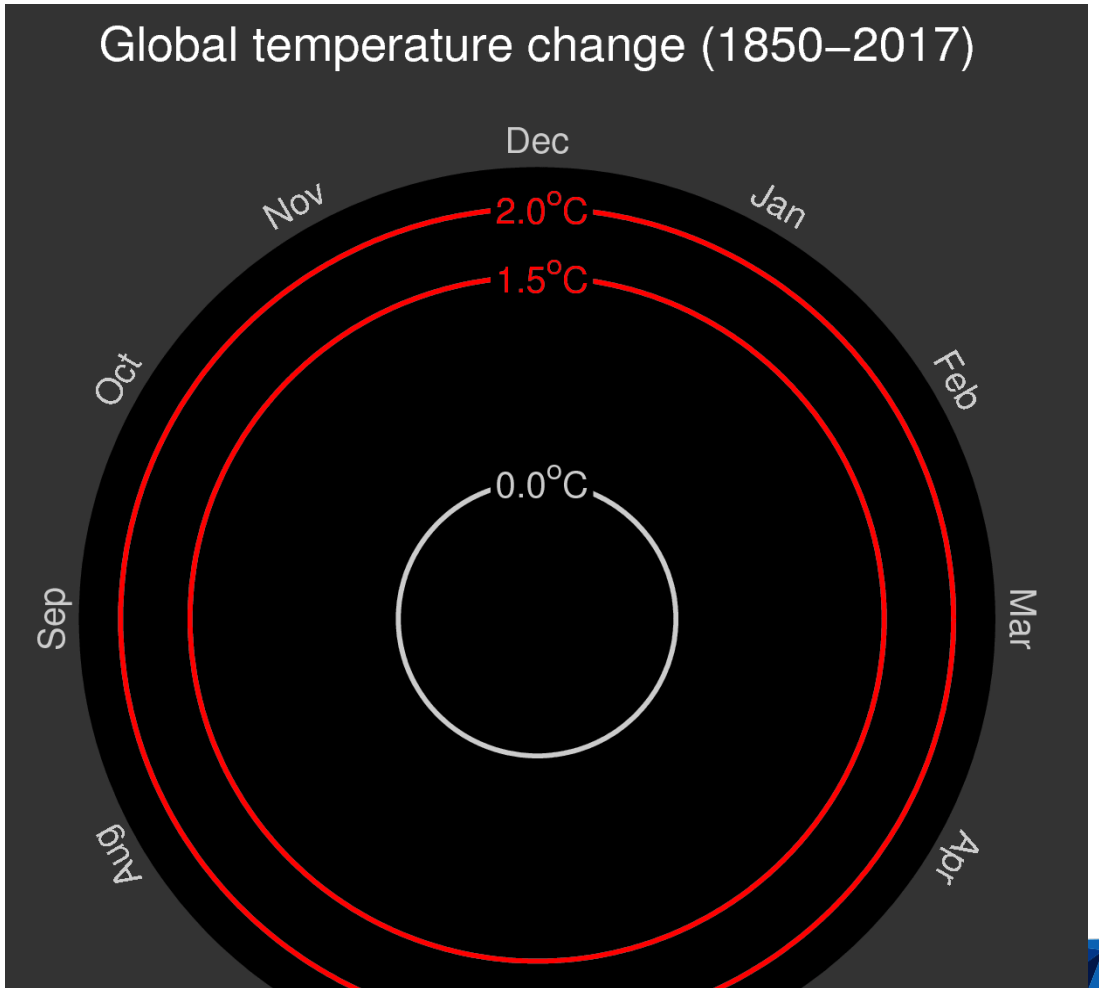
Potential for GHG reduction from shipping

Elizabeth Lindstad and Torstein Bø
SINTEF Ocean AS

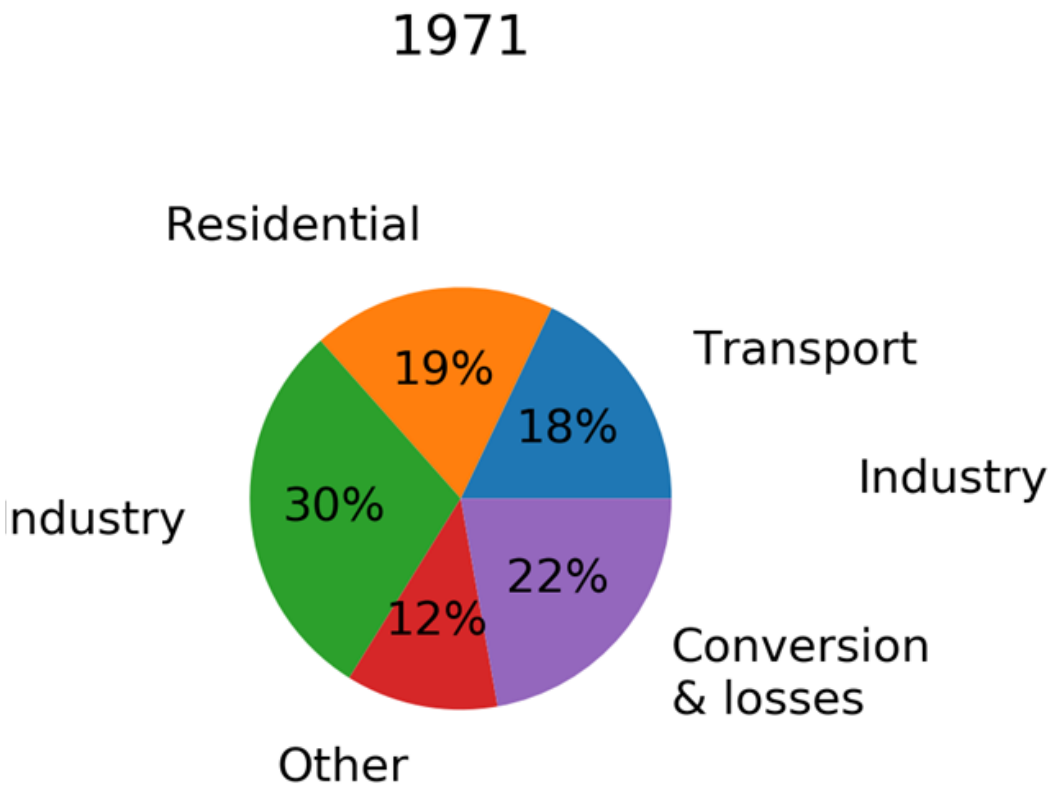
Increased Energy usuage (Fossile) -> Increases CO_2 concentration in the atmosphere and the temperature



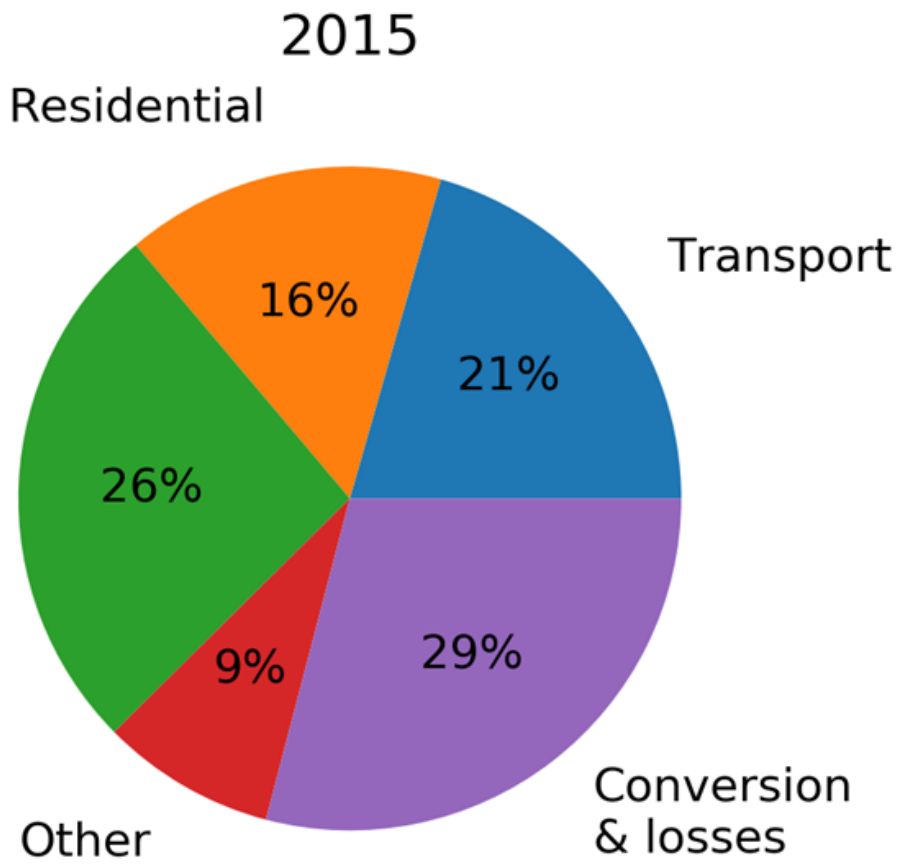




World Energy Consumption 1971 – 2015 Source: www.iea.org

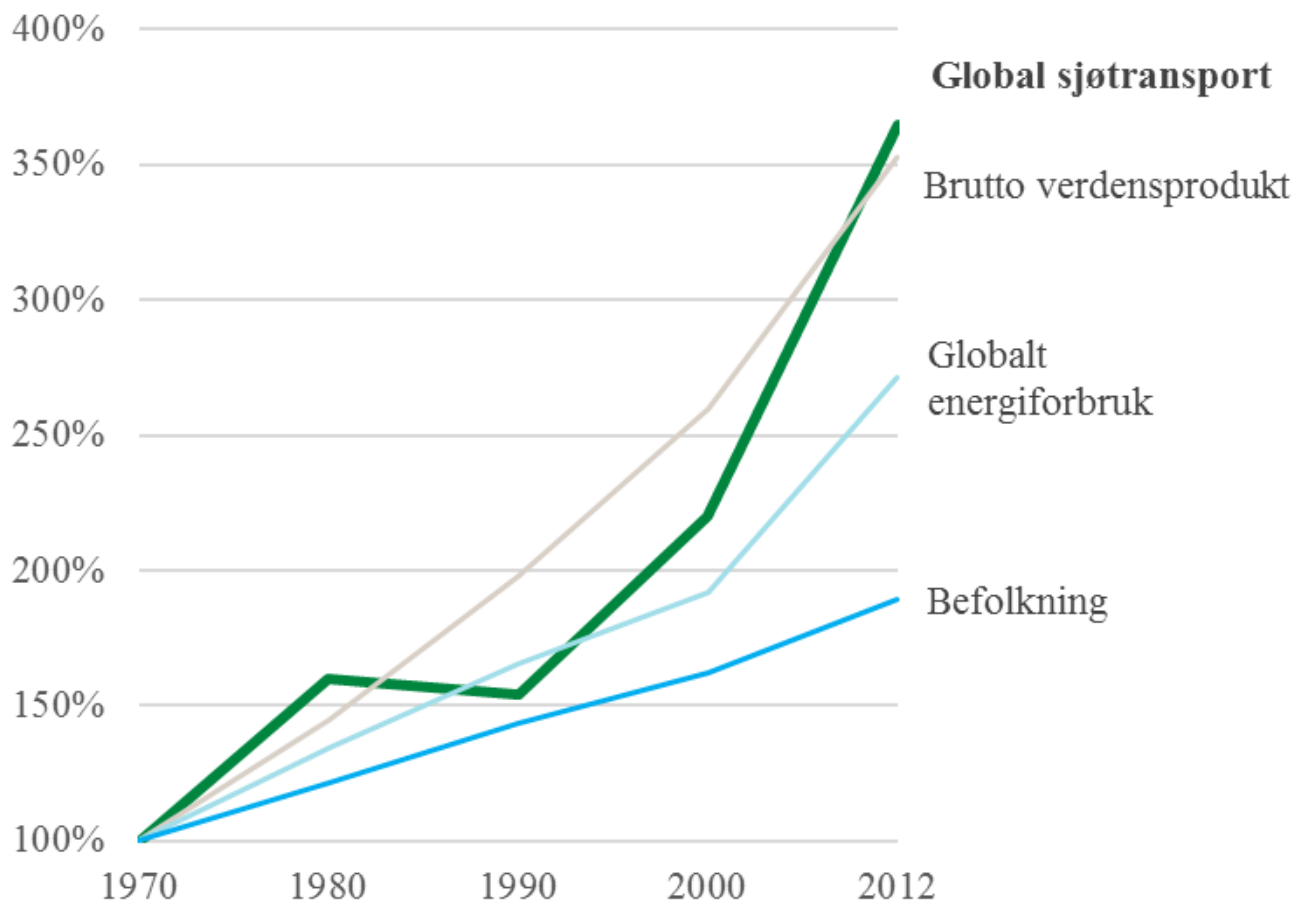


5 523 Mtoe



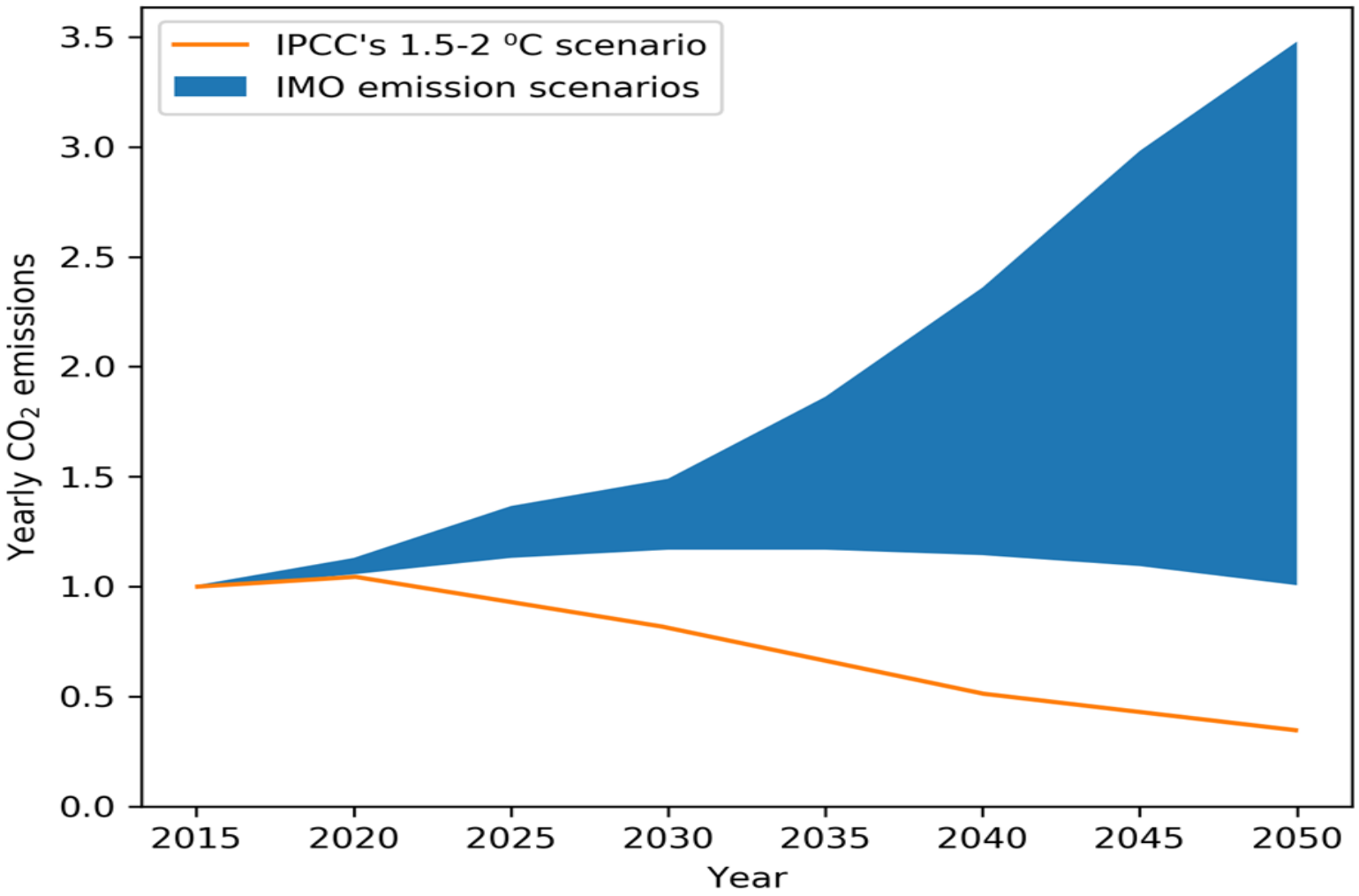
13 647 Mtoe

Global Development 1970 – 2012



Sources: UNCTAD (2014), IEA (2014), Lindstad (2013), Eskeland and Lindstad 2016)

Development of shipping emissions up to 2050 for 16 different scenarios developed by the Third IMO GHG study

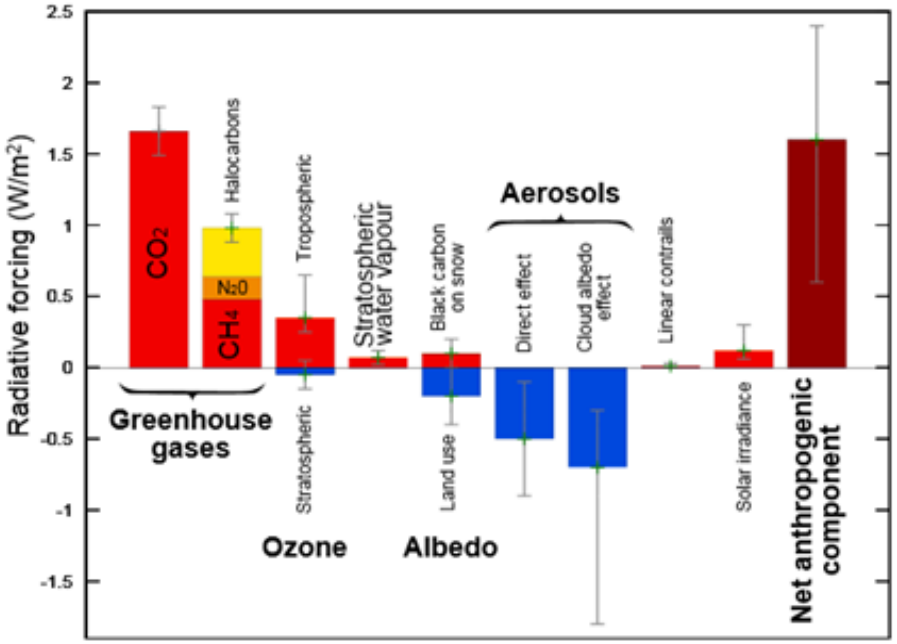


Source: Smith et al. (2014) and IPCC (2013)

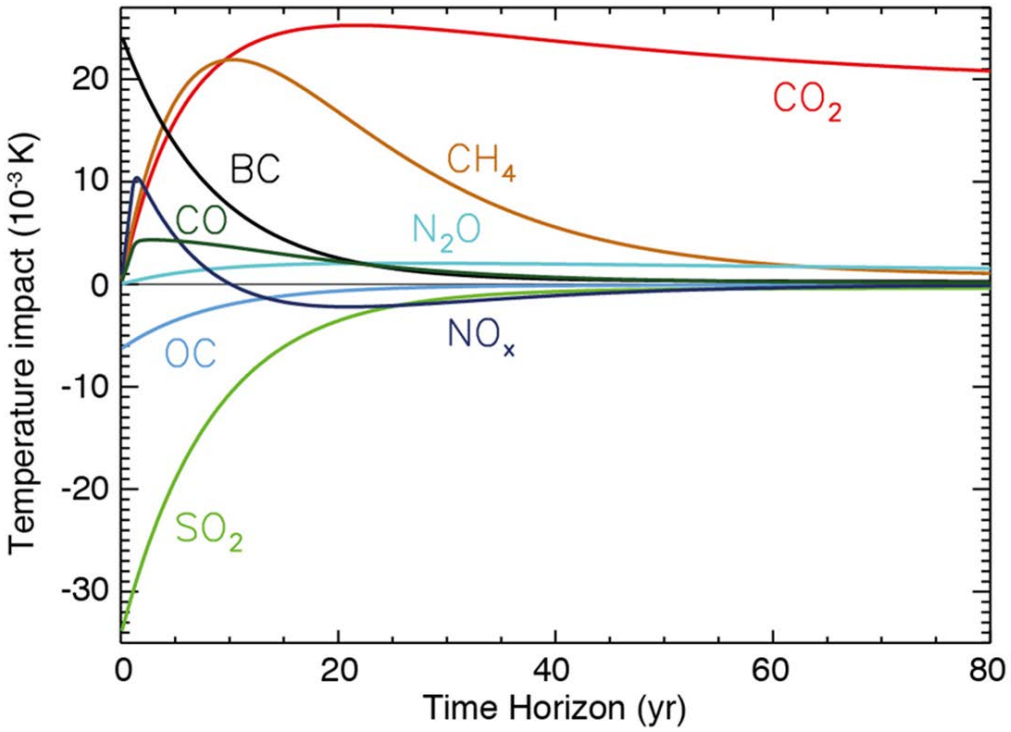
Shipping & Climate change

- Emissions effect both local pollution and climate change.
- Combined regulation is an economical and technical challenge for the shipping industry.
- Alternative fuels such as LNG, LPG, Methanol or Hydrogen is one tempting option for meeting these new requirements.
- IMO aims to (April 2018):
  - Reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out.
  - Reduce CO2 emissions per transport work, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008.

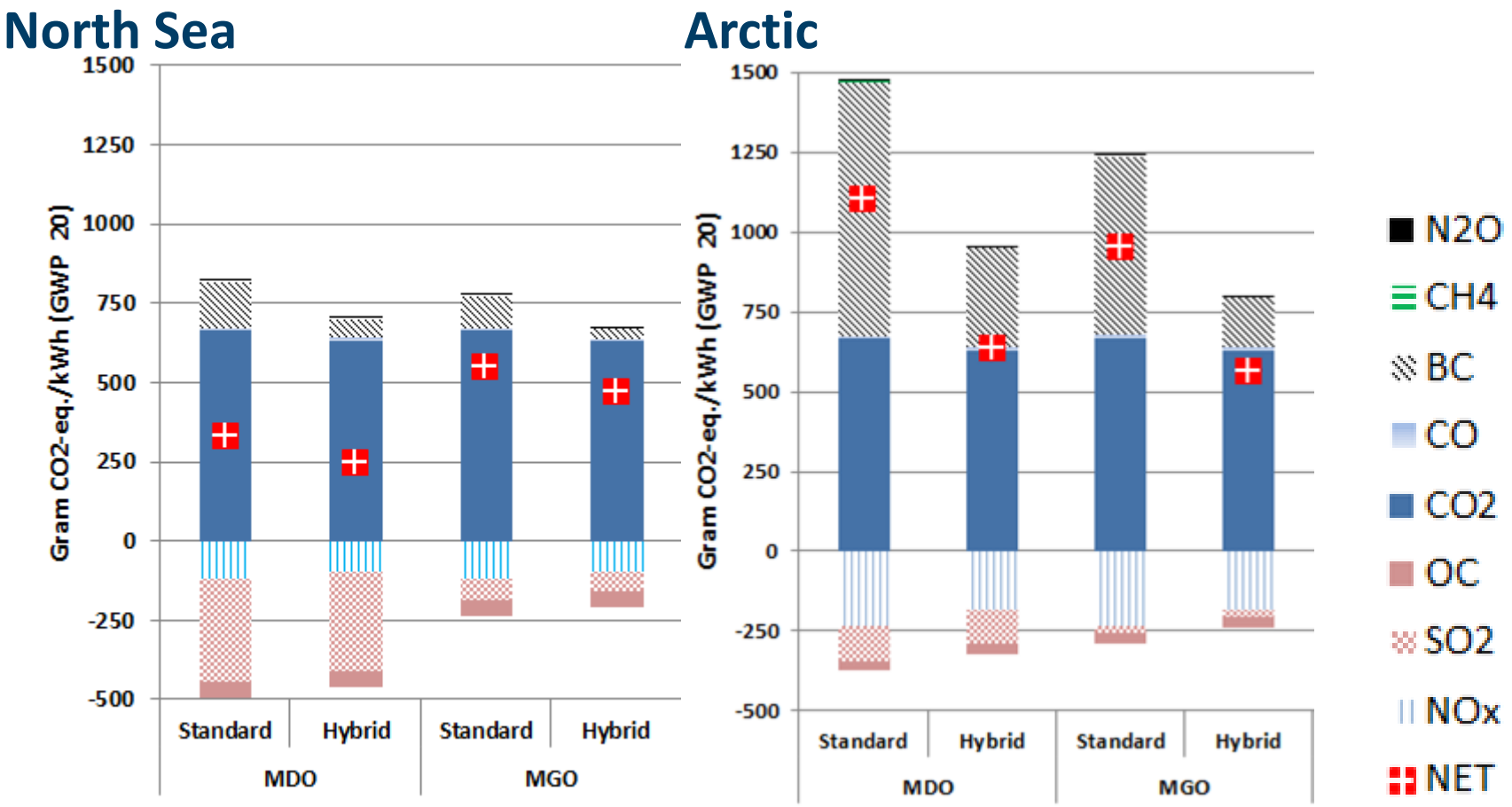
Greenhouse gasses are more than CO2



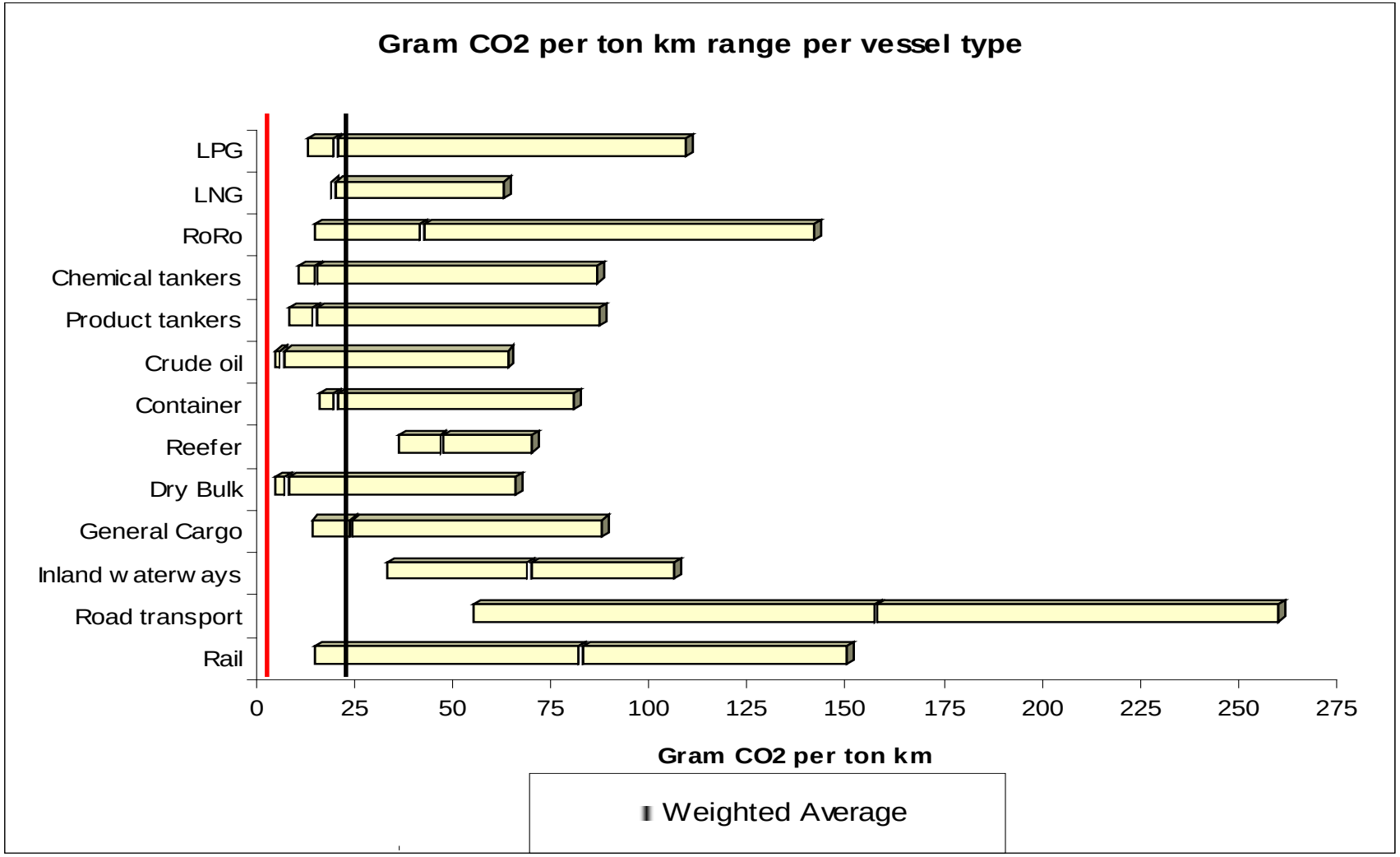
Source: Leland McInnes based on IPCC Natural Drivers of Climate Change, Figure SPM.2, in IPCC AR4 WG1 2007.



Location is important



Source: Lindstad, H., E., Sandaas, I., 2016 *Emission and Fuel Reduction for Offshore Support Vessels through Hybrid Technology*. Journal of Ship Production and Design, Vol. 32, No. 4, Nov 2016, pp. 195–205



Source: Lindstad and Mørkve 2009 and Lindstad 2018

Mains options for reducing shippings GHG

Use less energy

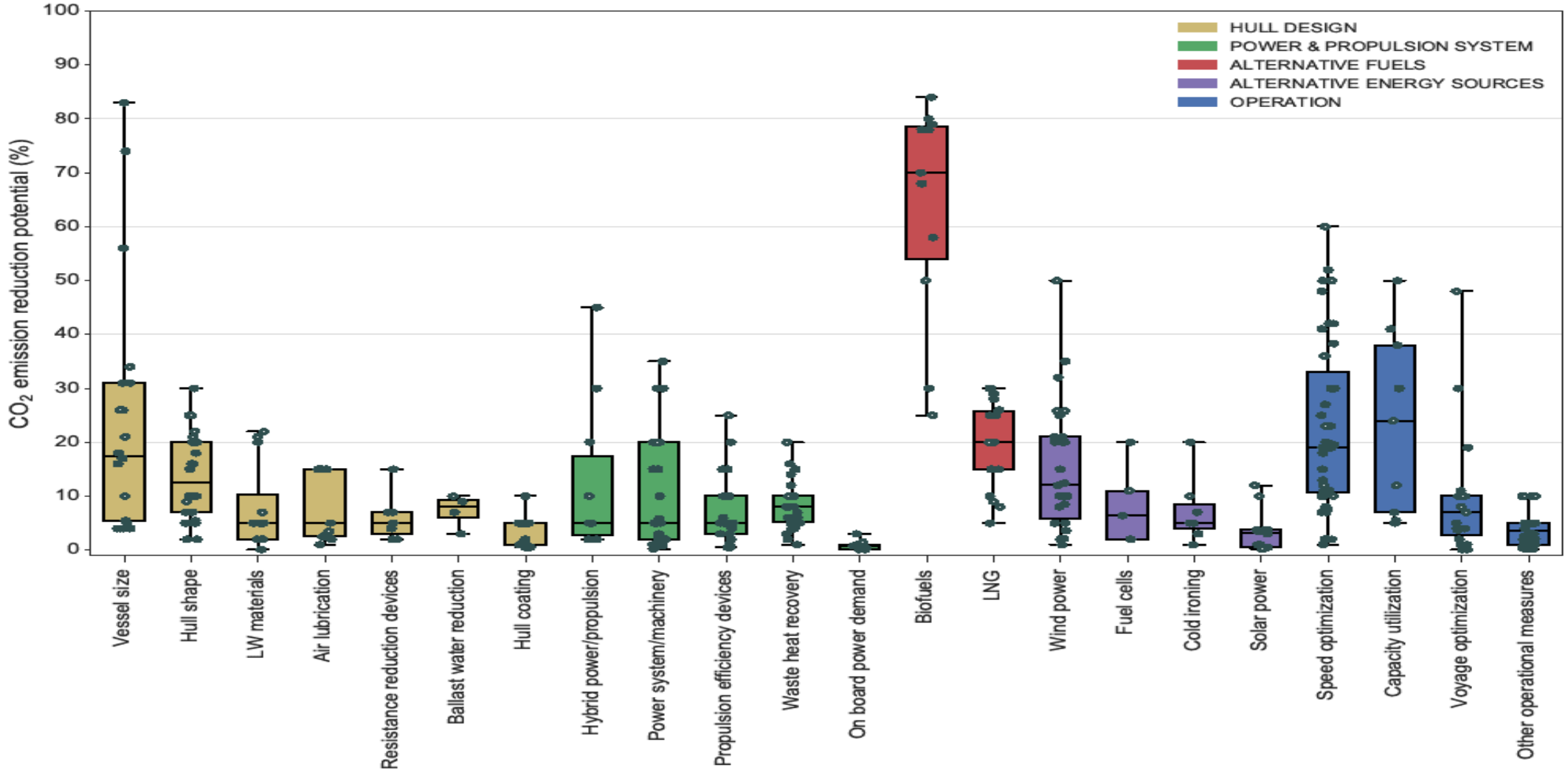
- Hull design and other technologies (same speed, less power)
- Logistic (new speed, route, etc)

Lower GHG emission/energy

- Alternative fuels
- Renewable energy

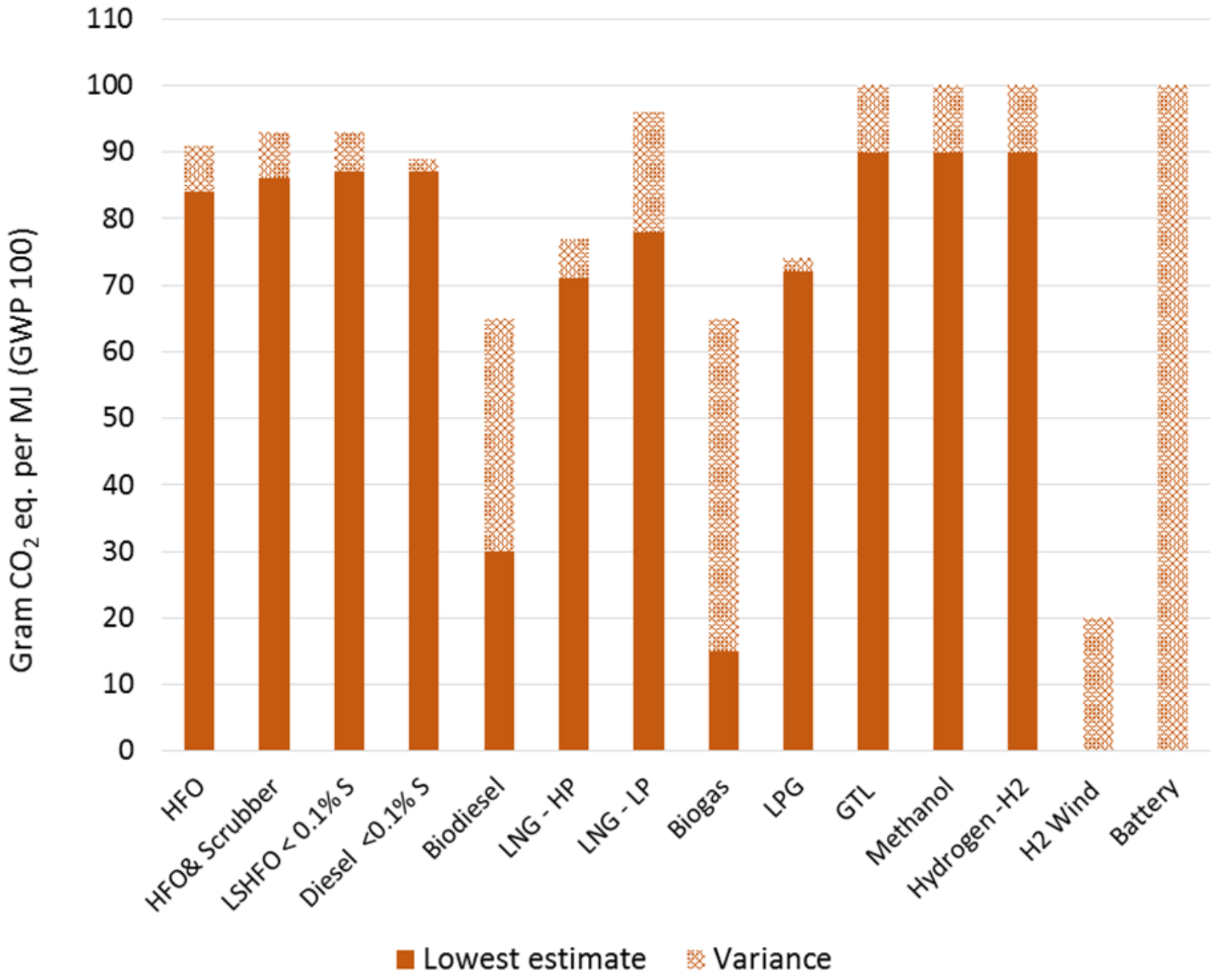
State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review

Evert A. Bouman [a,*], Elizabeth Lindstad [b], Agathe I. Rialland [b], Anders H. Strømman [a]



Well to Wake (WTW) emissions for alternative versus traditional fuels in shipping

– a Review of published studies



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Open Hatch Carriers & General Cargo

Conventional Designs versus – a Step Change

A parametric feasibility study

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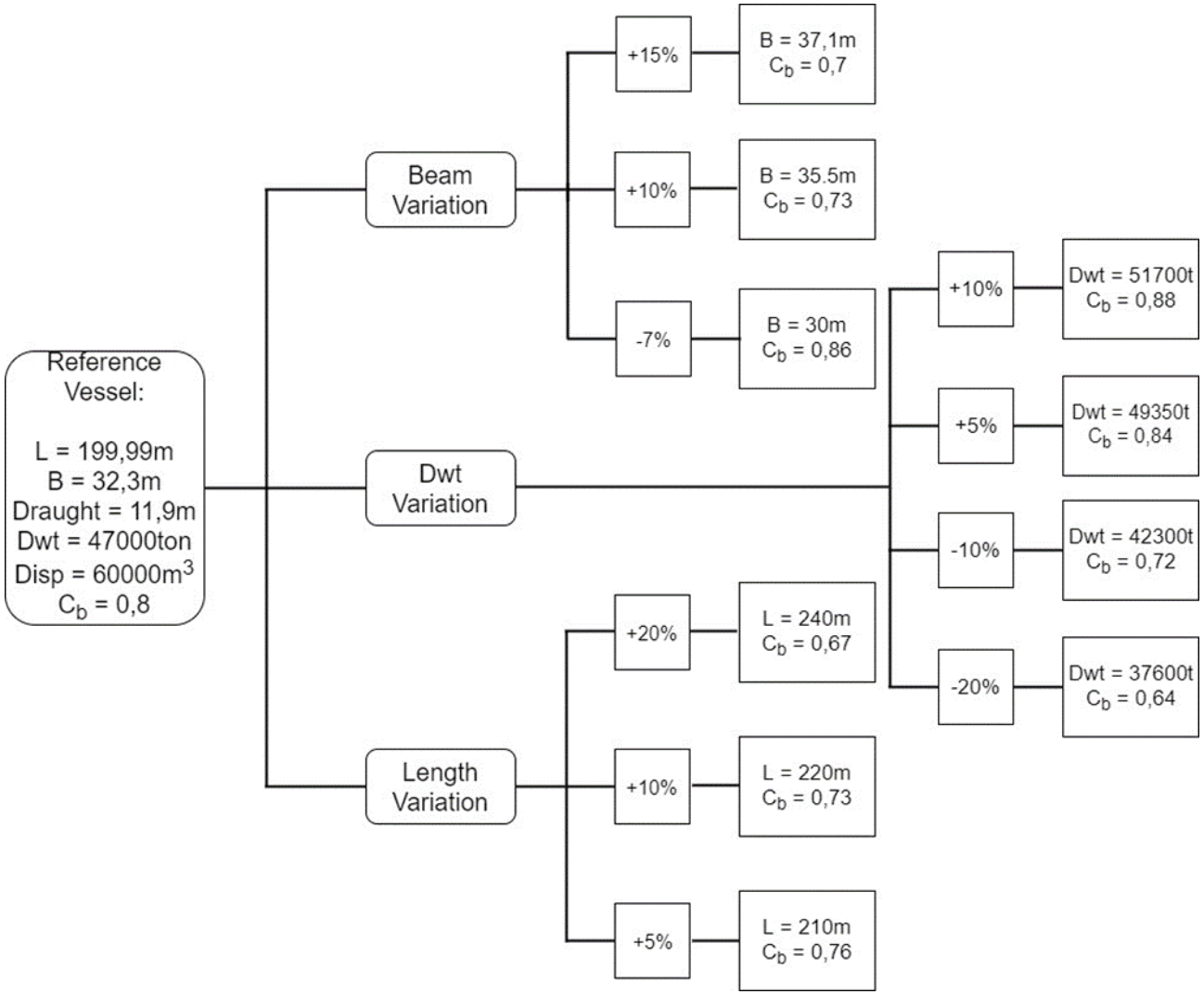
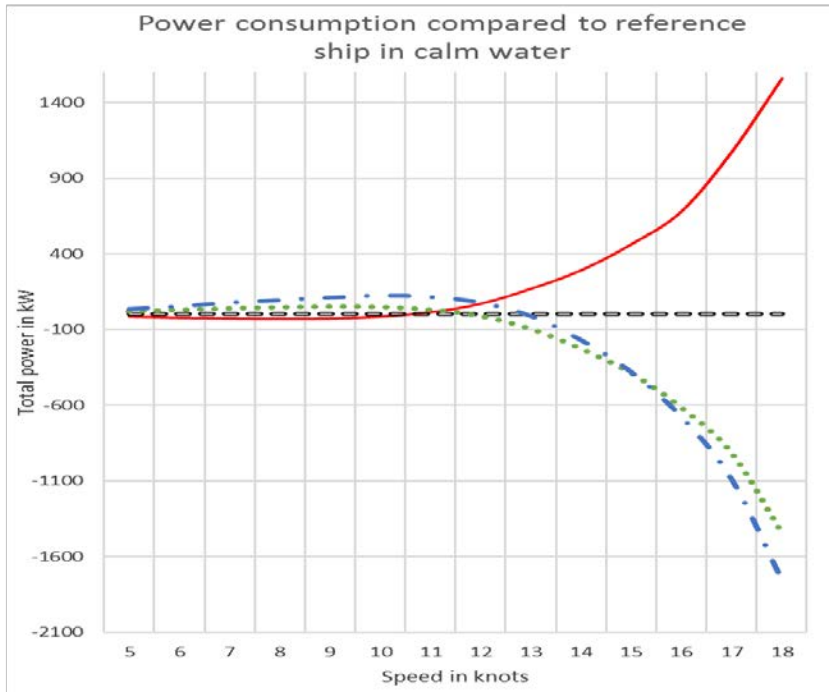
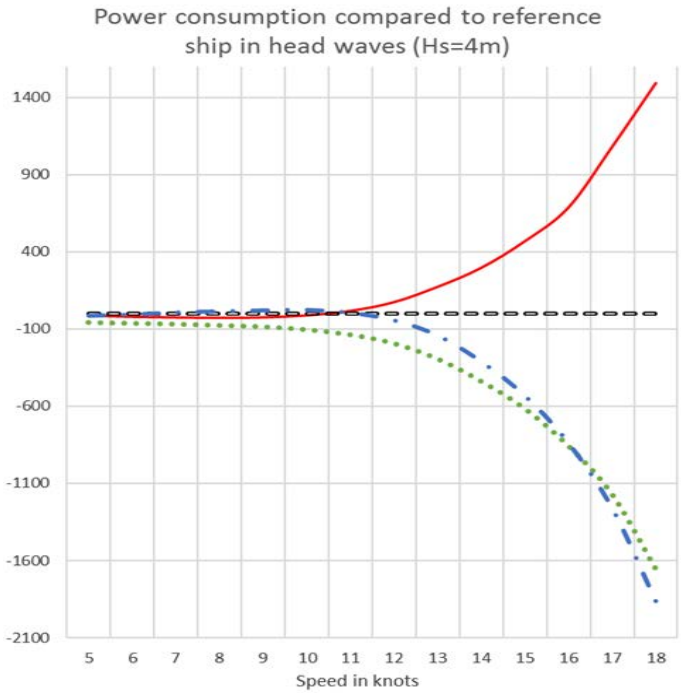
Designs analysed in the parametric feasibility study



Increasing beam keeping DWT constant





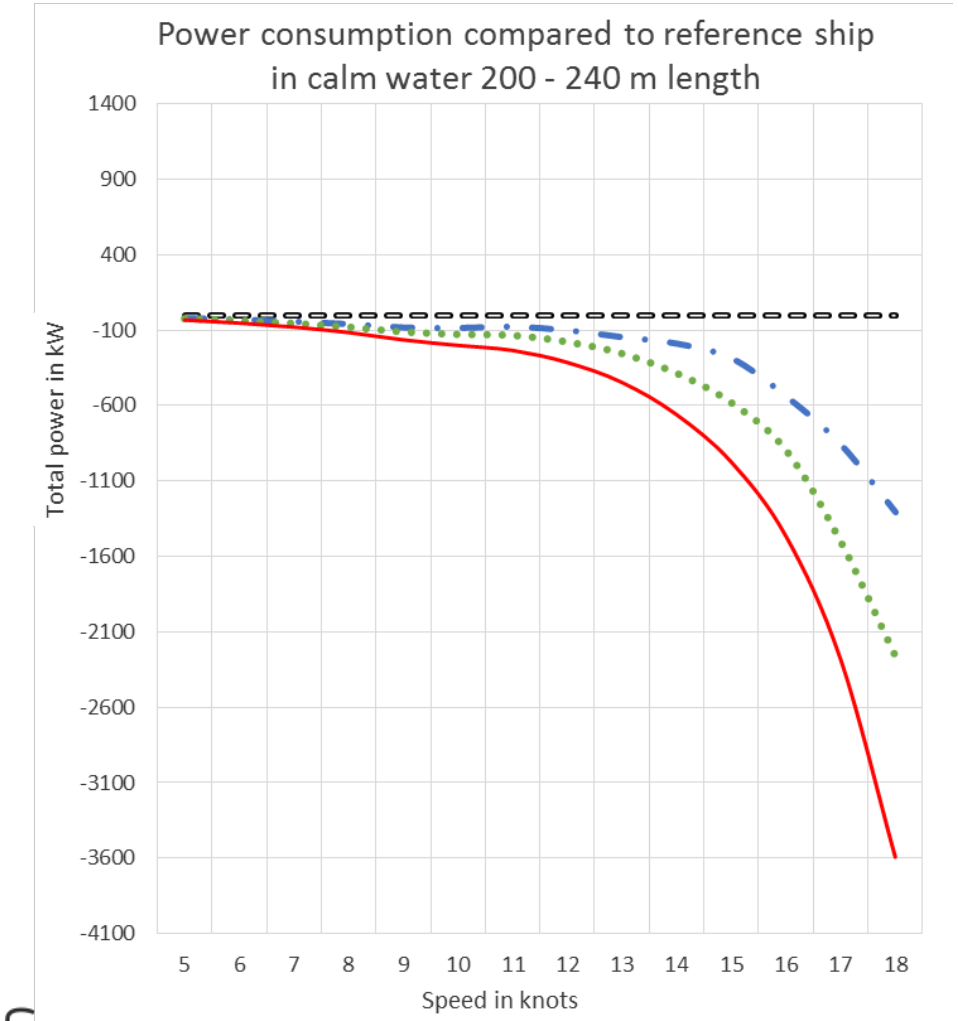
B=30m

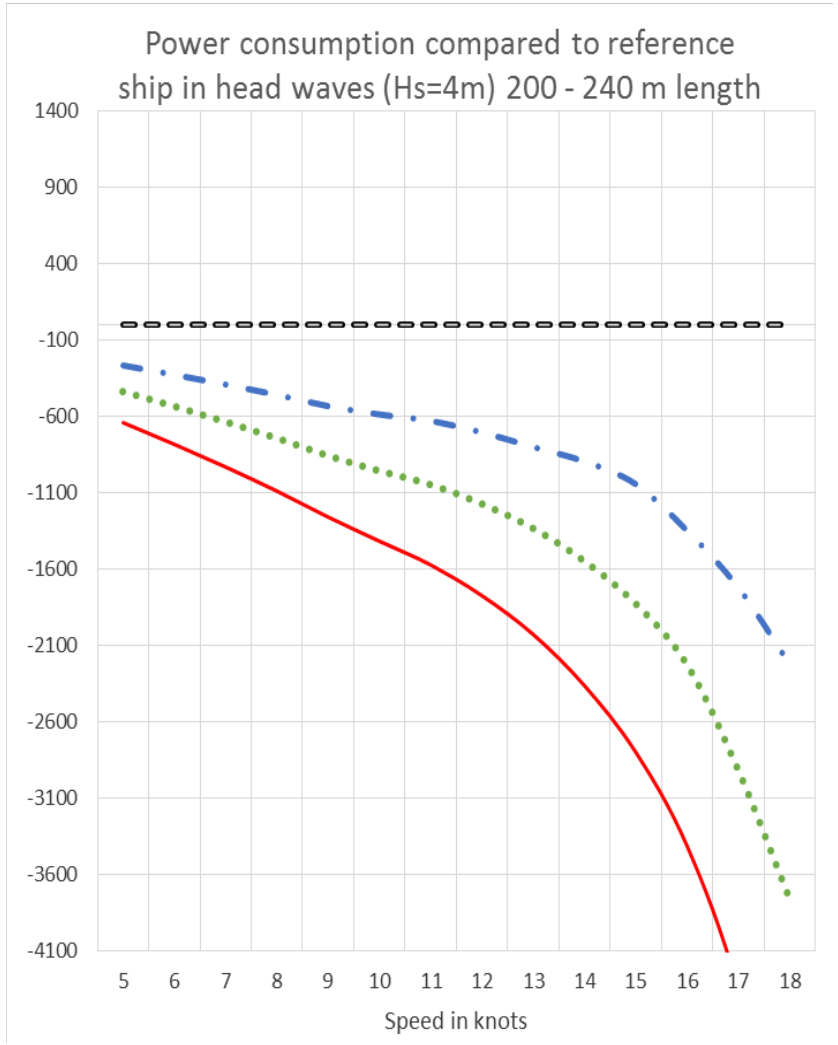
REF

B=35.5m

B=37.1m

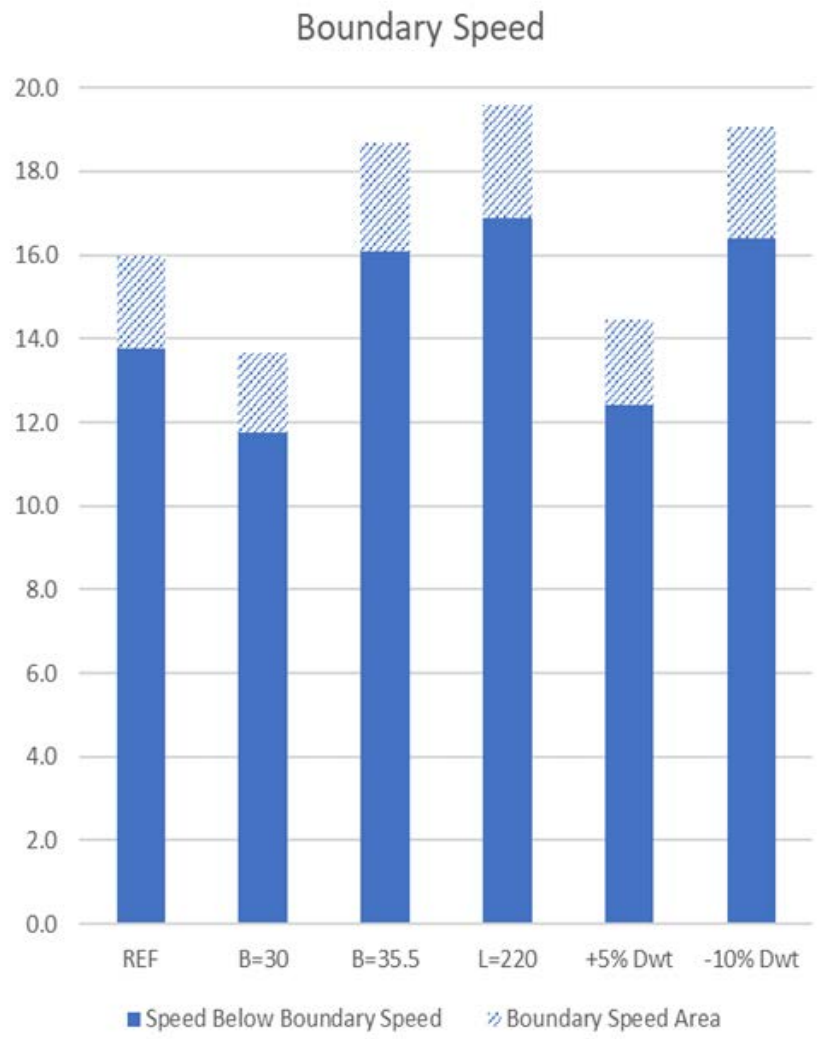
Increasing length keeping DWT constant



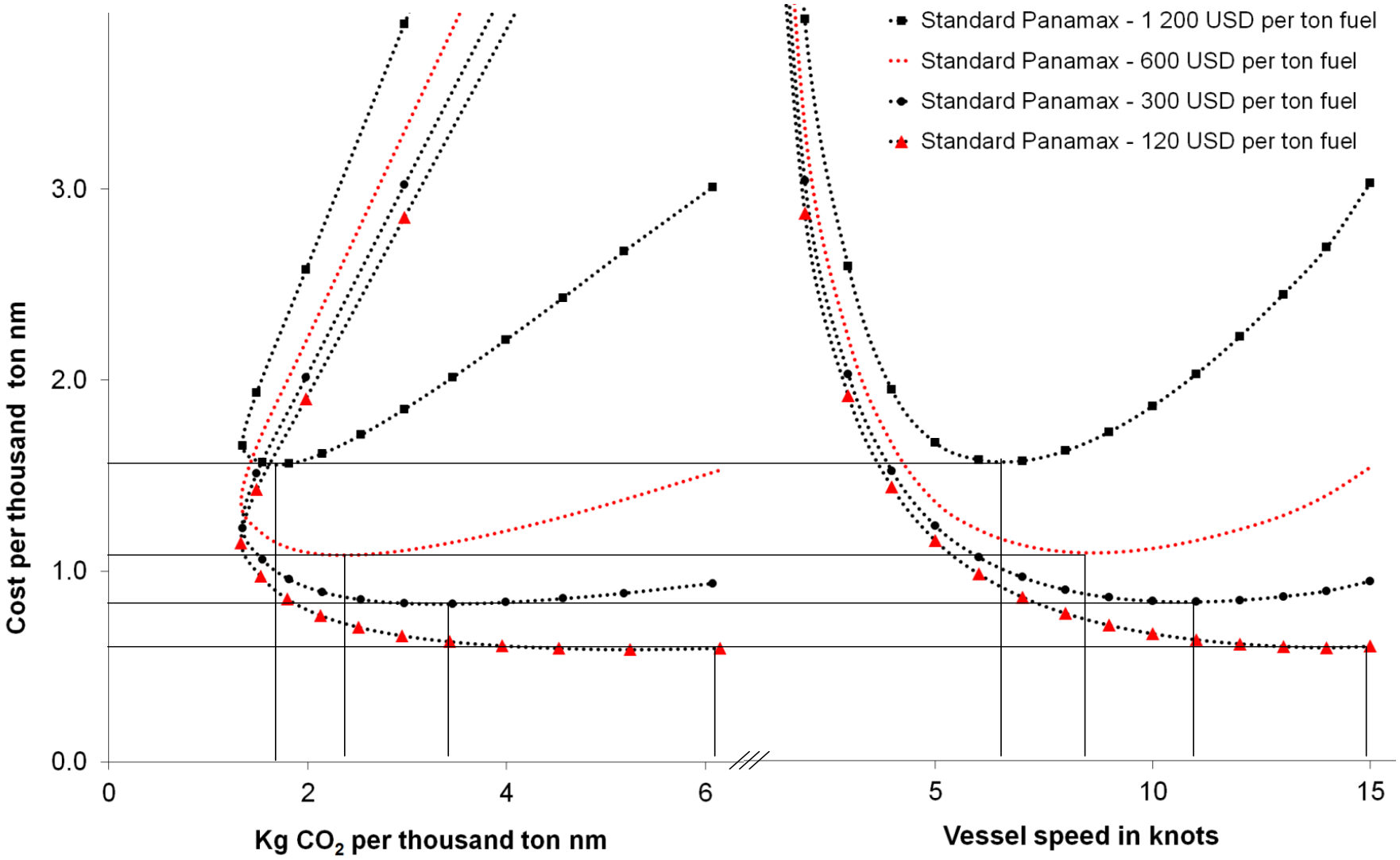


Summary – Comparing alternative designs with same cargo capacity

- **Required voyage speed** is a main input parameter to the design process.
- Vessels are frequently pushed far beyond their boundary speeds.
- Increasing length gives largest reduction, and this advantage increases in Real SEA



Operational Speed is a function of fuel price and capex cost



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Alternative Hybrid Powertrains to meet EEDI Requirements

Elizabeth Lindstad, Torstein Ingebrigtsen Bø

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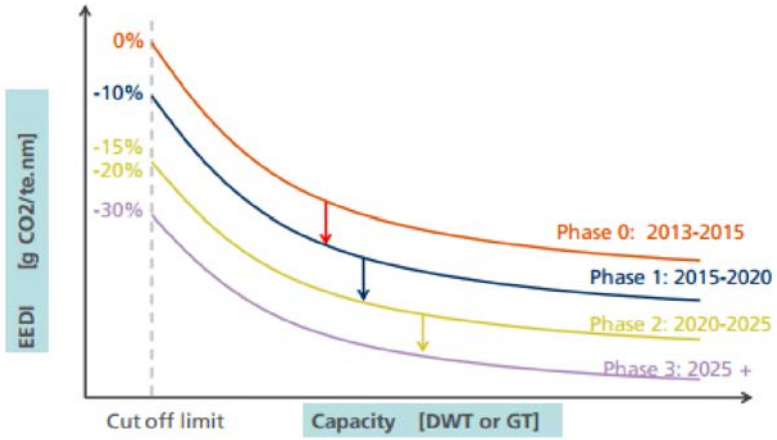
Case study

- Aframax tanker (110 000 dwt)
- How can EEDI requirements be met?

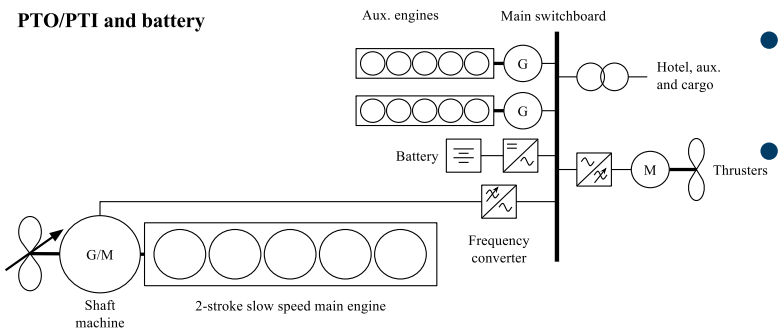
$$EEDI = \frac{CO_2}{\text{DWT} \times \text{Distance}}$$



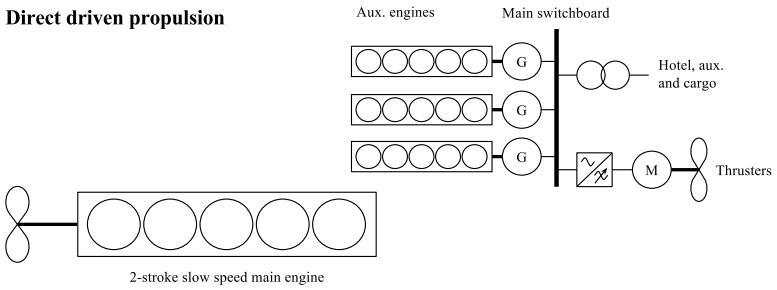
Technologies

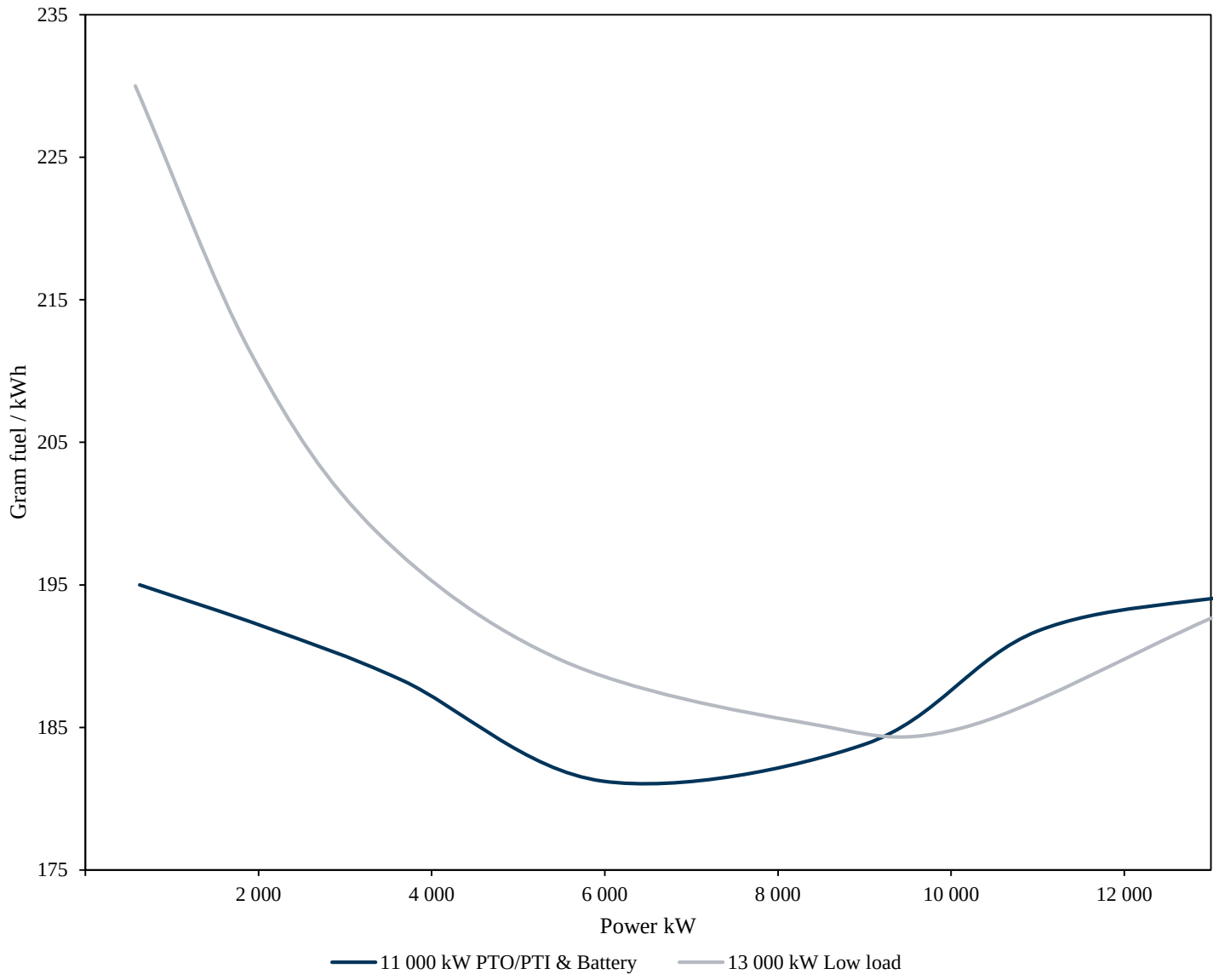
- Hybrid (PTO/PTI/Battery)
- LNG (5 – 20 % less CO_2-eq)
- Slender hull

Hybrid



- Downsize main engine
- Use shaft motor during severe weather

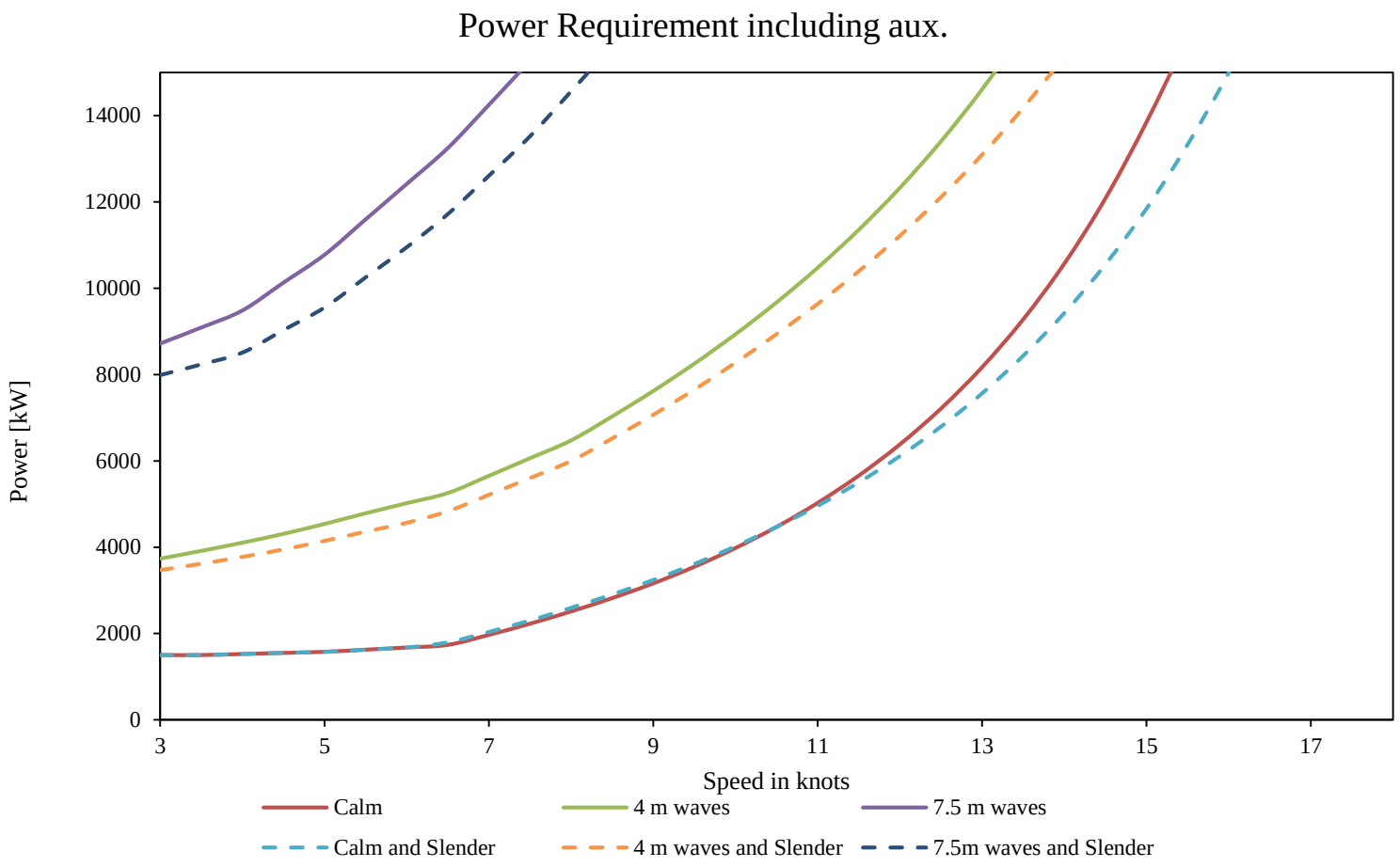



235
225
215
205
195
185
175
Gram fuel / kWh
2 000
4 000
6 000
8 000
10 000
12 000
Power kW
11 000 kW PTO/PTI & Battery
13 000 kW Low load

LNG

- 20 % reduction in CO_2
- Methan slip:
  - 5 - 20 % reduction in greenhouse gass emissions

Slender hull



EEDI

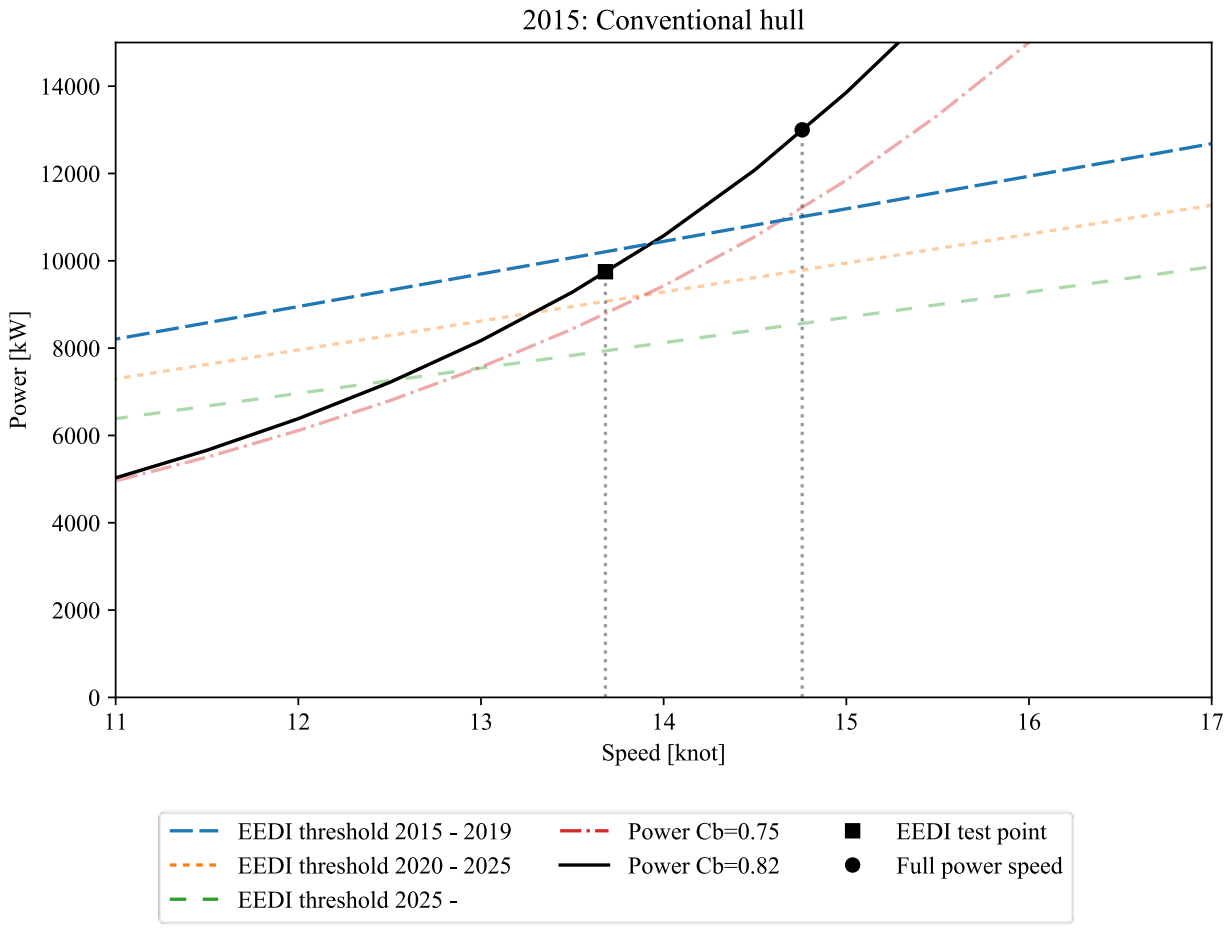
$$EEDI = \frac{CO_2}{\text{DWT} \times \text{Distance}}$$

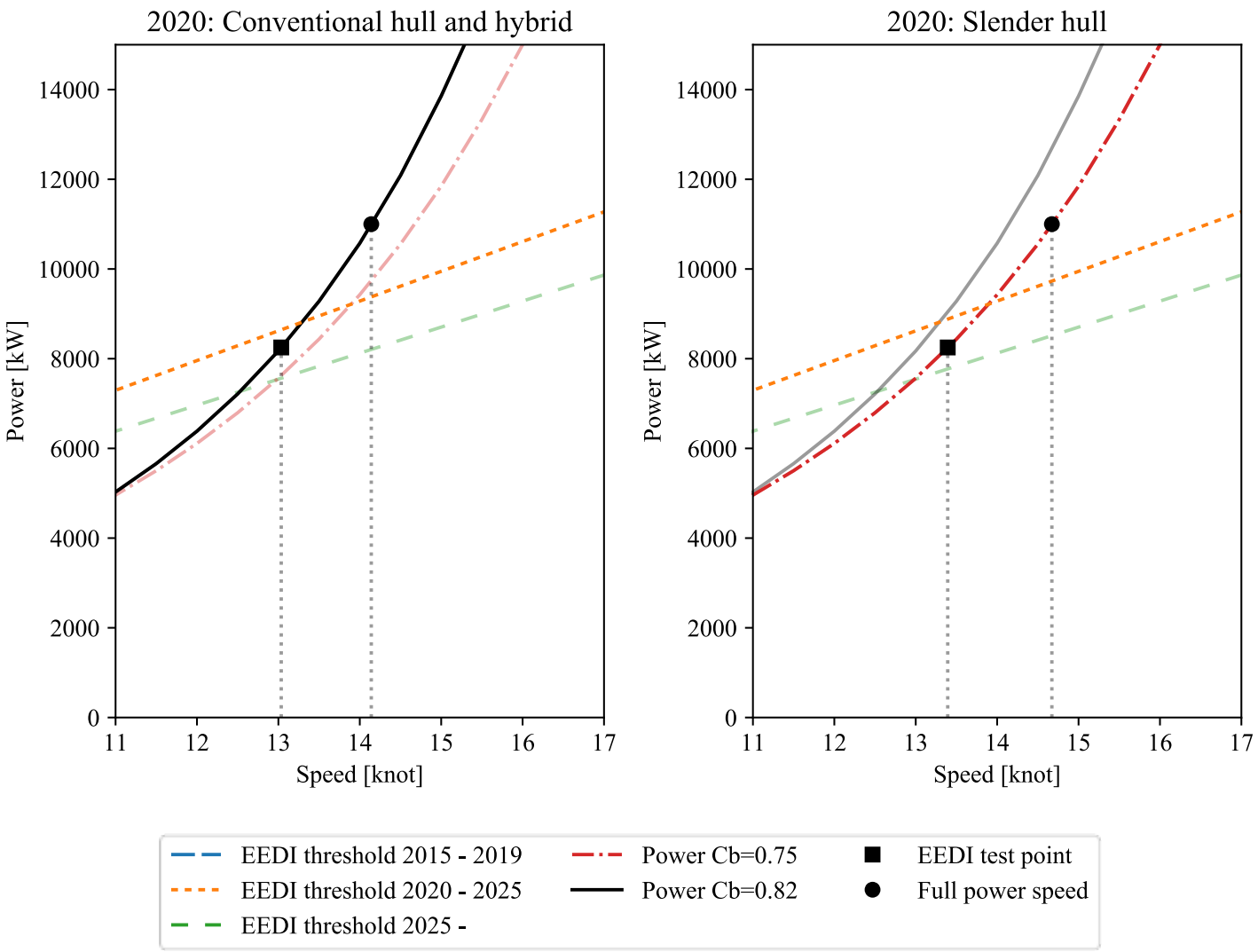
$$= \frac{P_{installed} \times 75\% \times \text{SFC} \times \text{Carbon factor} \times \text{time}}{DWT \times \text{speed} \times \text{time}}$$

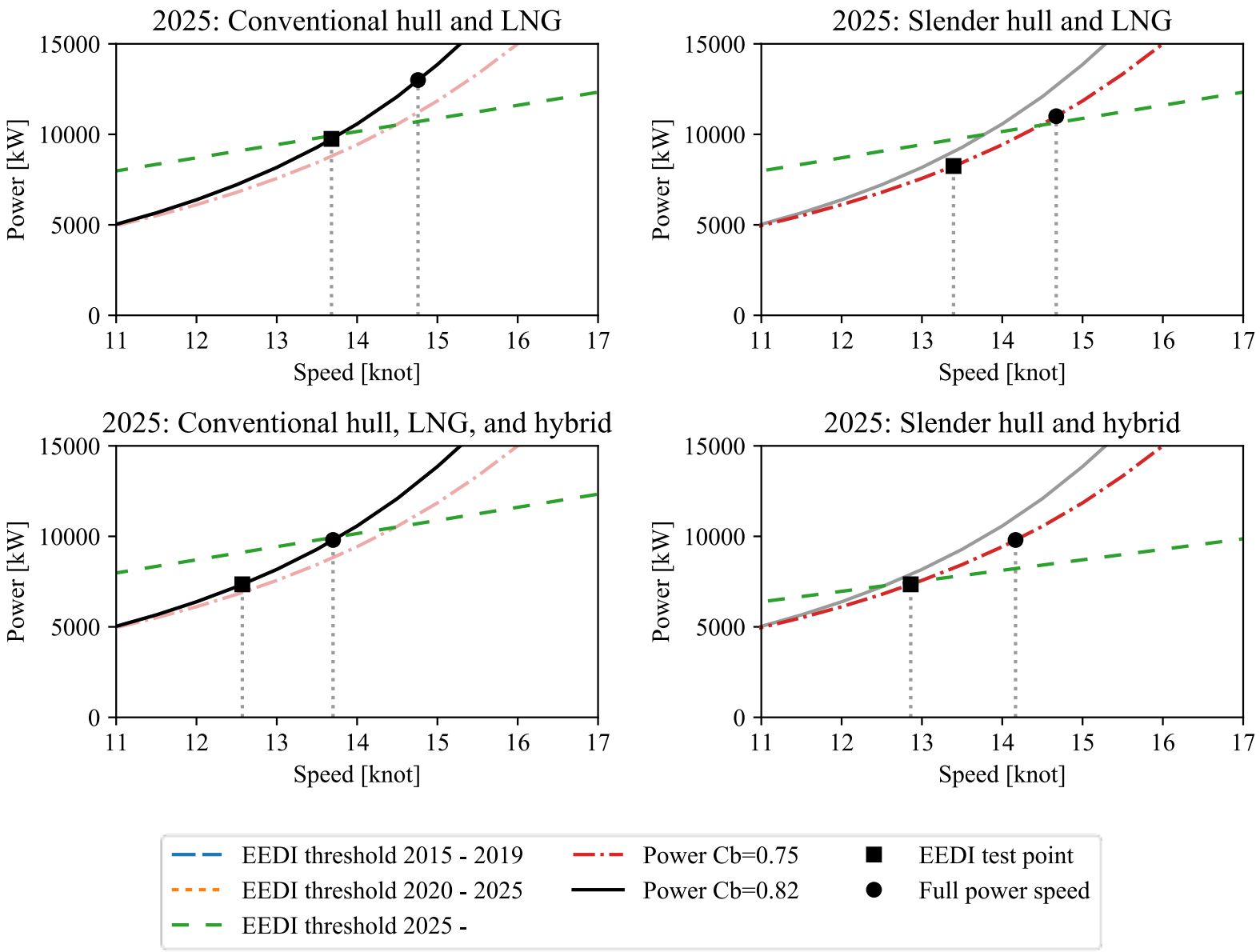
$$= \frac{P_{installed}}{\text{speed}} \frac{75\% \times \text{SFC} \times \text{Carbon factor}}{DWT}$$

$$EEDI \geq \frac{P_{installed}}{\text{speed}} \text{Constant}$$

$$\frac{EEDI}{Constant} \text{speed} \geq P_{installed}$$


2015: Conventional hull
Power [kW]
Speed [knot]
0
2000
4000
6000
8000
10000
12000
14000
11
12
13
14
15
16
17
EEDI threshold 2015 - 2019
EEDI threshold 2020 - 2025
EEDI threshold 2025 -
Power Cb=0.75
Power Cb=0.82
EEDI test point
Full power speed


2020: Conventional hull and hybrid
2020: Slender hull
Power [kW]
Speed [knot]
0
2000
4000
6000
8000
10000
12000
14000
11
12
13
14
15
16
17
EEDI threshold 2015 - 2019
EEDI threshold 2020 - 2025
EEDI threshold 2025 -
Power Cb=0.75
Power Cb=0.82
EEDI test point
Full power speed



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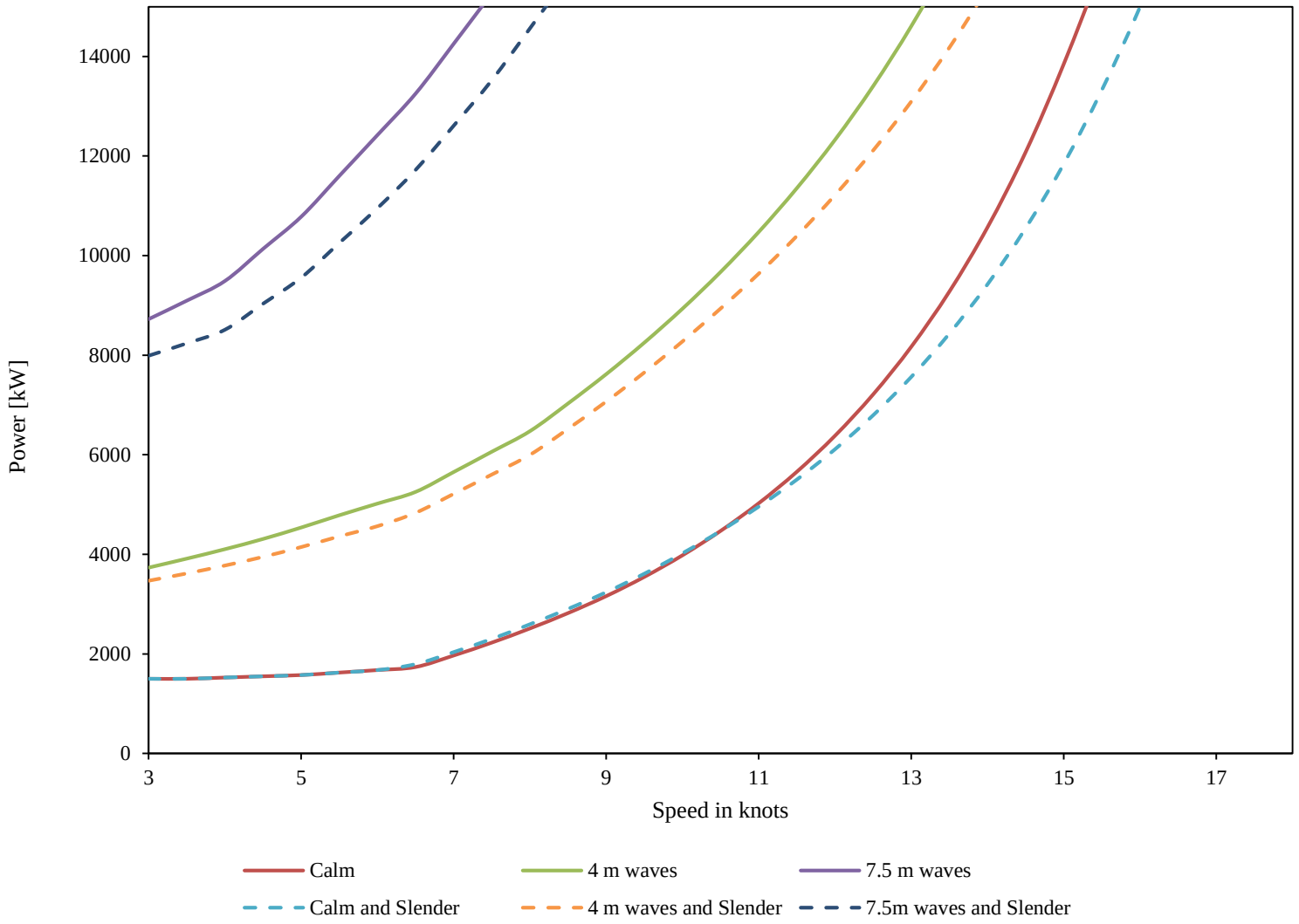
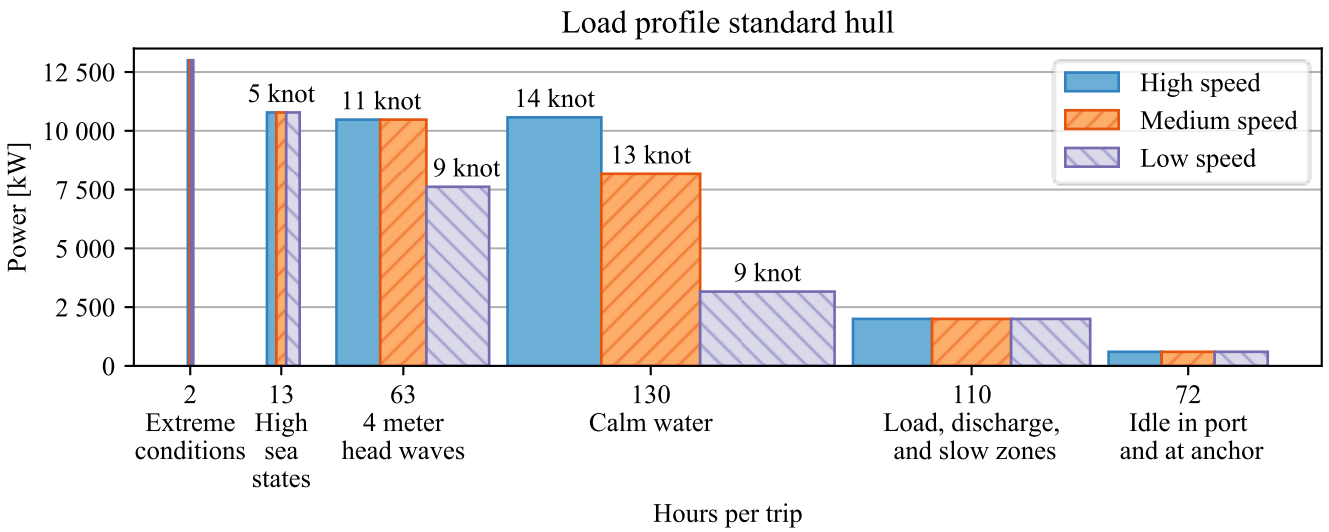
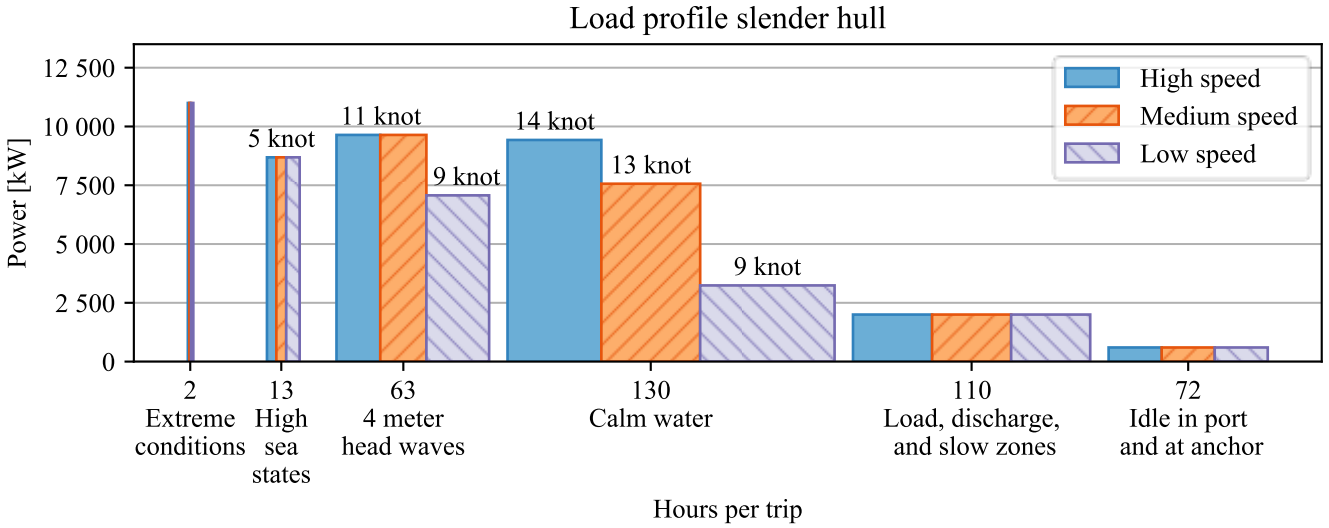
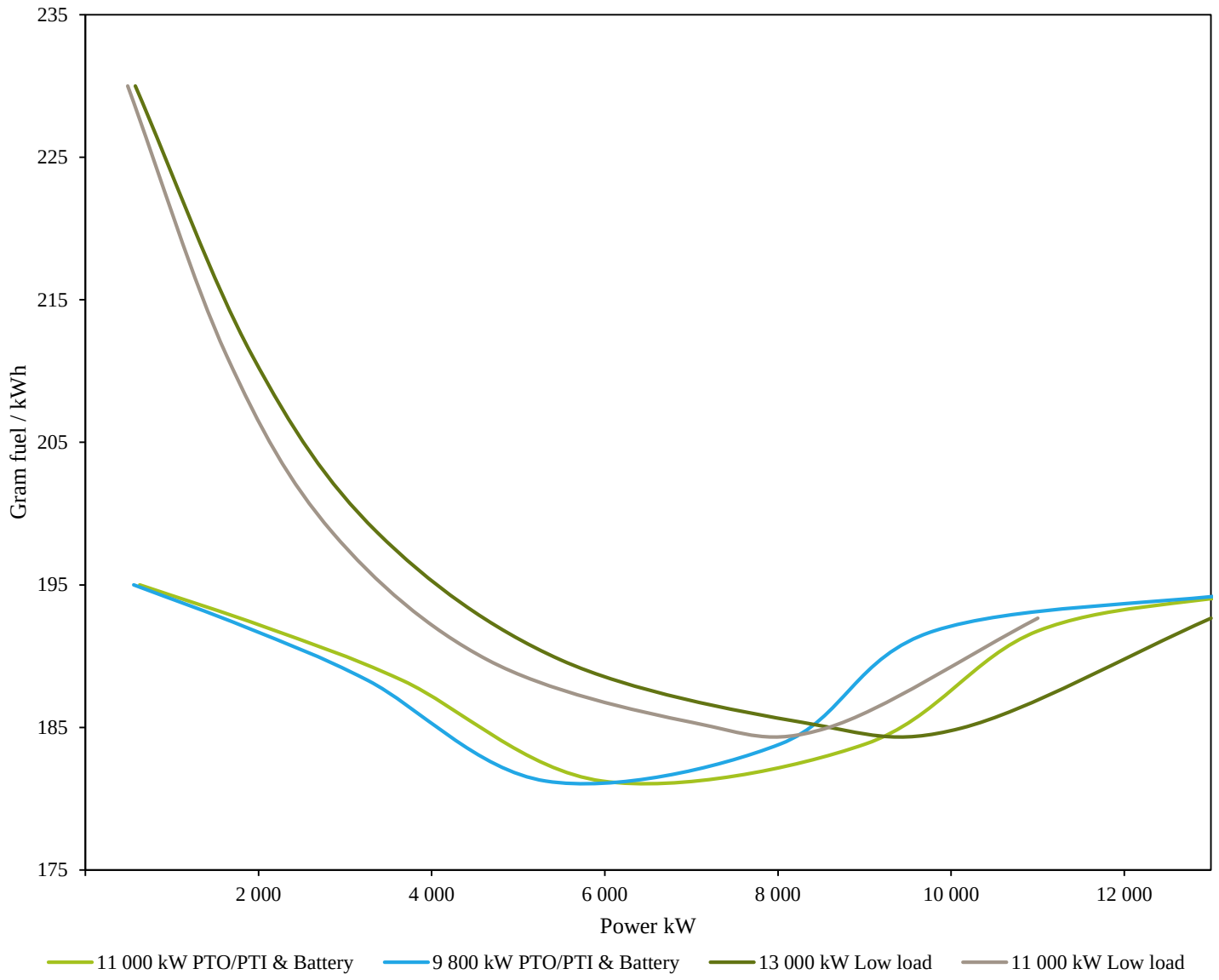
Calculation of Cost and Emission

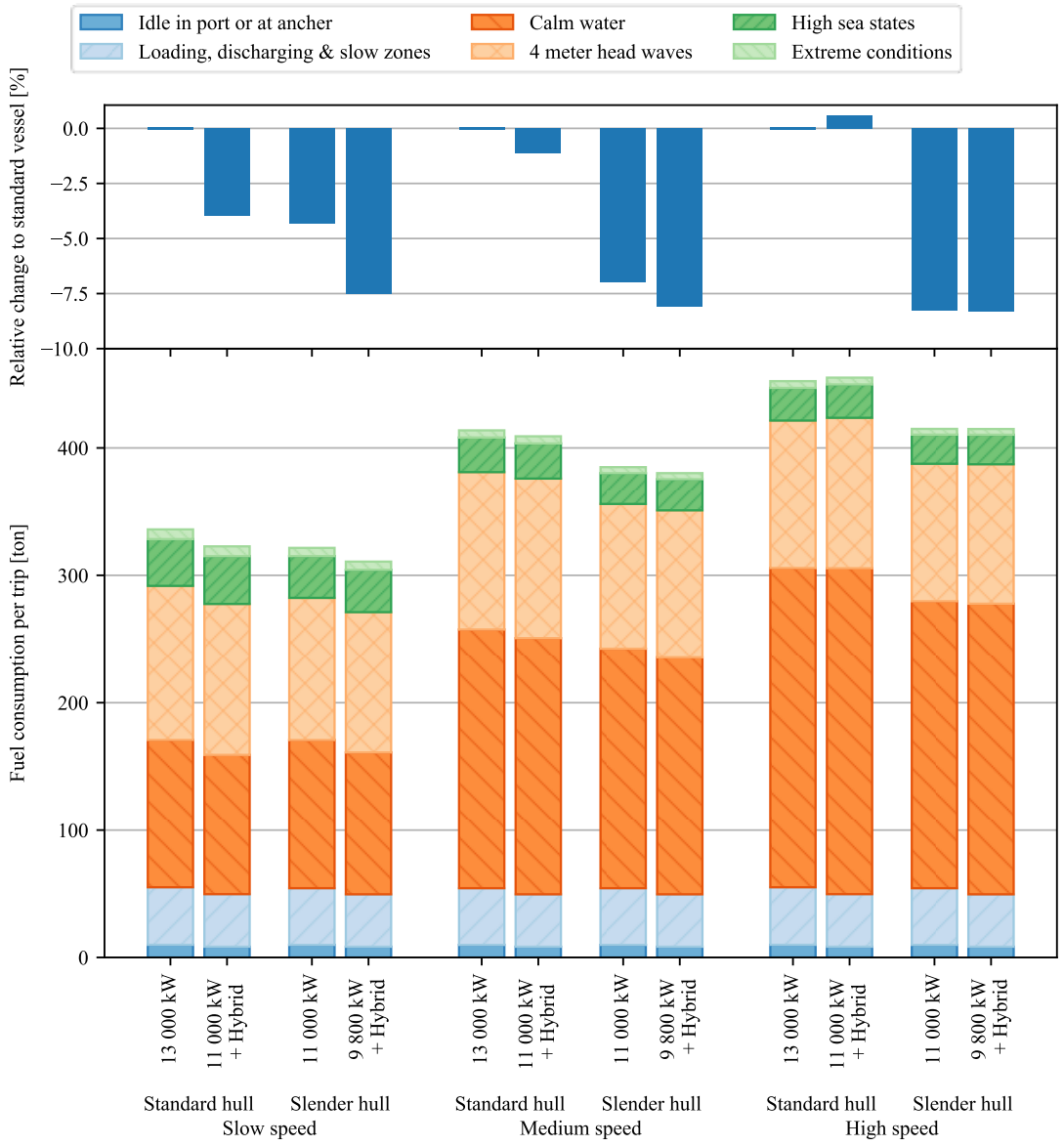
Power Requirement including aux.

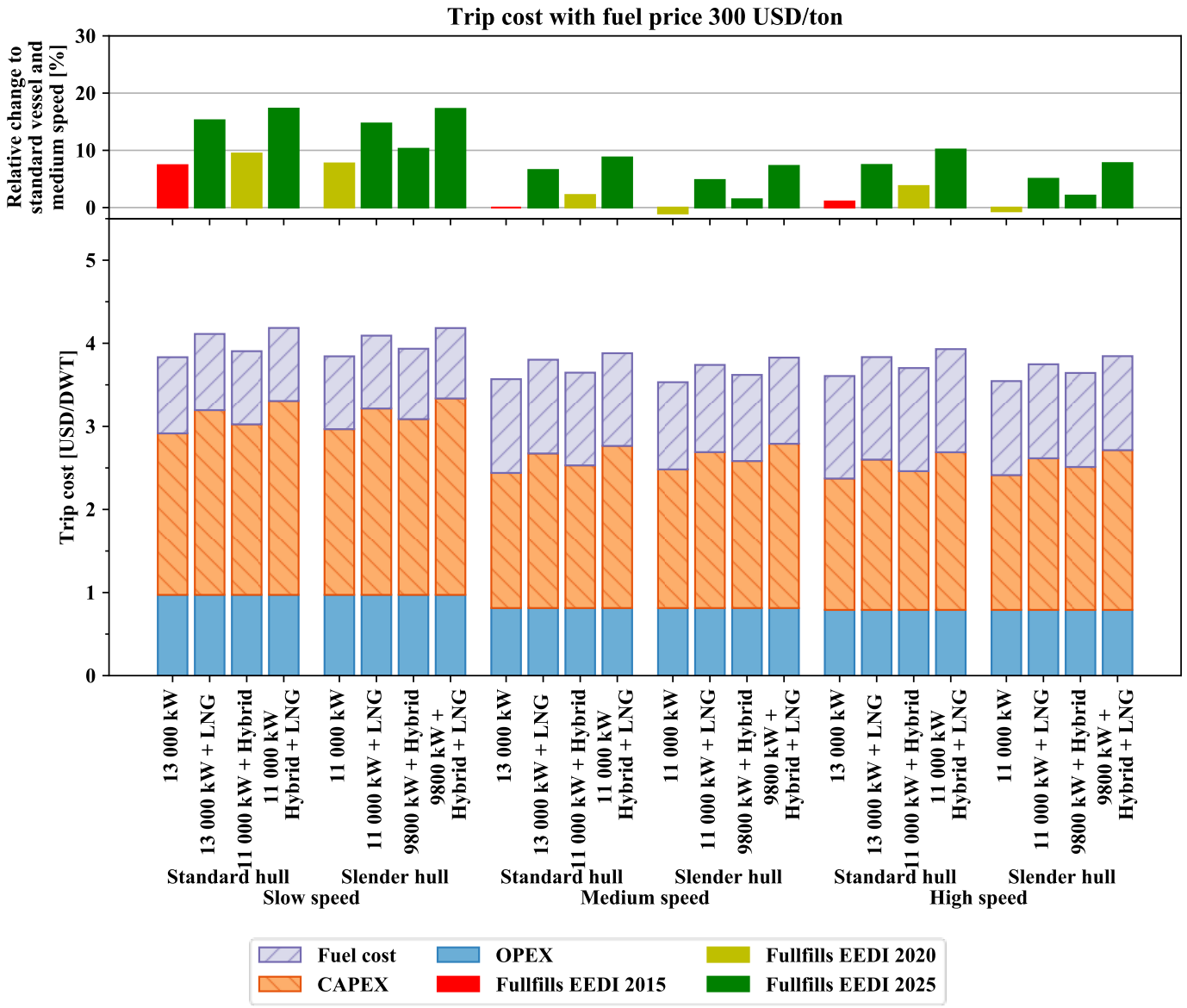



Load profile standard hull
Power [kW]
12 500
10 000
7 500
5 000
2 500
0
5 knot
11 knot
9 knot
14 knot
13 knot
9 knot
High speed
Medium speed
Low speed
2
Extreme conditions
13
High sea states
63
4 meter head waves
130
Calm water
110
Load, discharge, and slow zones
72
Idle in port and at anchor
Hours per trip


Load profile slender hull
Power [kW]
12 500
10 000
7 500
5 000
2 500
0
5 knot
11 knot
9 knot
14 knot
13 knot
9 knot
High speed
Medium speed
Low speed
2
Extreme conditions
13
High sea states
63
4 meter head waves
130
Calm water
110
Load, discharge, and slow zones
72
Idle in port and at anchor
Hours per trip


235
225
215
205
195
185
175
Gram fuel / kWh
2 000
4 000
6 000
8 000
10 000
12 000
Power kW
11 000 kW PTO/PTI & Battery
9 800 kW PTO/PTI & Battery
13 000 kW Low load
11 000 kW Low load


Idle in port or at ancher
Loading, discharging & slow zones
Calm water
4 meter head waves
High sea states
Extreme conditions
Relative change to standard vessel [%]
0.0
−2.5
−5.0
−7.5
−10.0
Fuel consumption per trip [ton]
400
300
200
100
0
13 000 kW
11 000 kW + Hybrid
11 000 kW
9 800 kW + Hybrid
Standard hull
Slender hull
Slow speed
Medium speed
High speed



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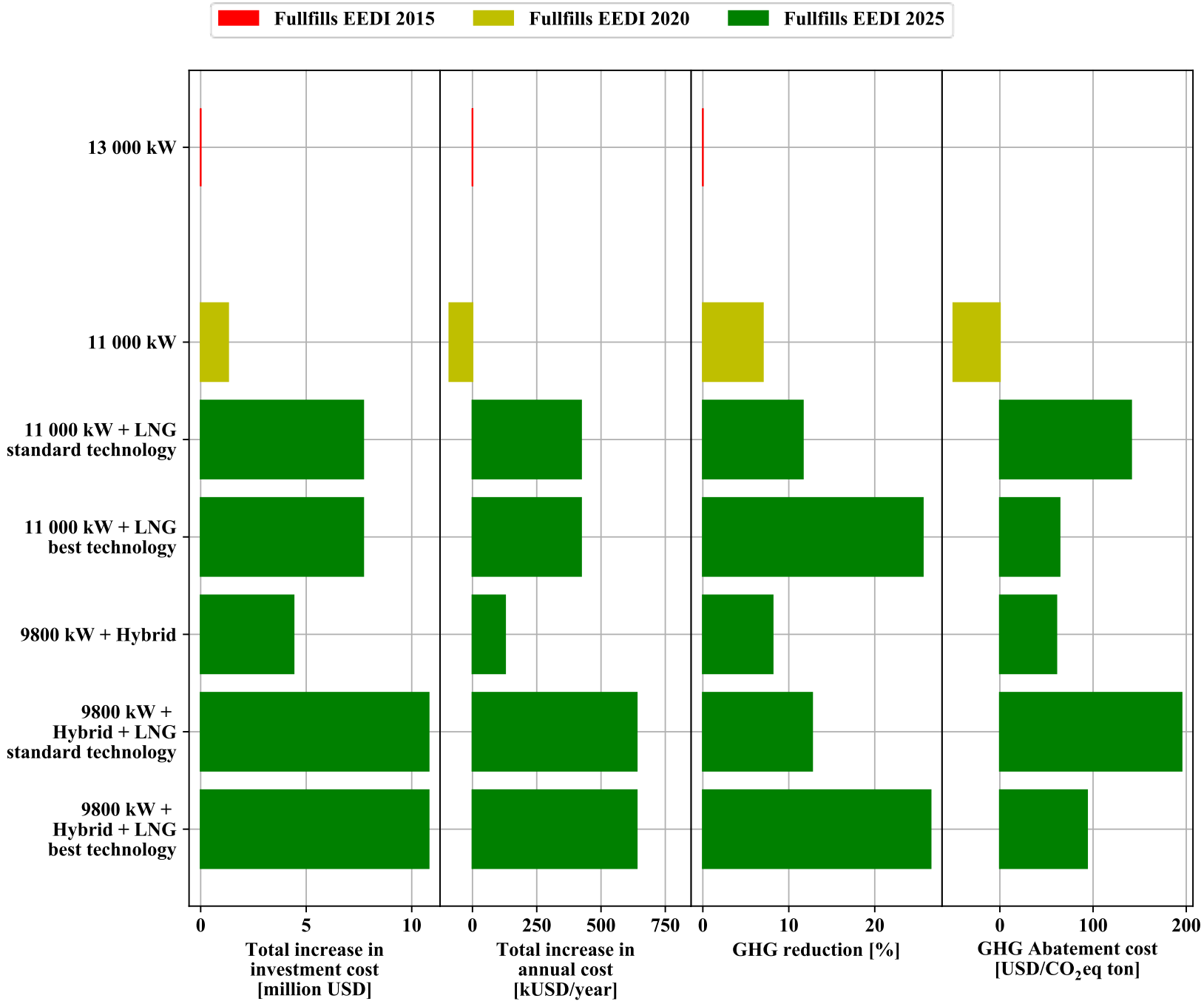
Conclusion



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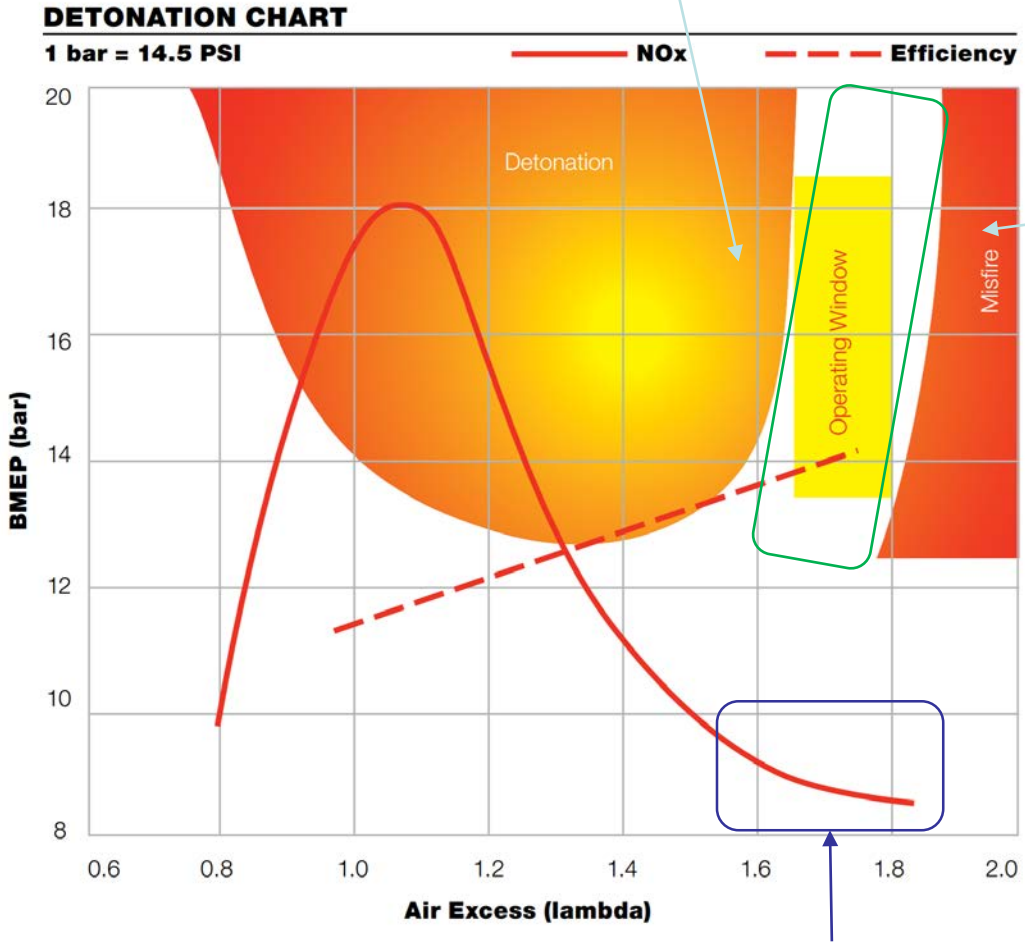
MPC based control of gas engine and battery

Torstein I. Bø (SINTEF), Erlend Vaktskjold (Rolls-Royce Bergen Engine),
Eilif Pedersen (NTNU), Olve Mo (SINTEF)

Otto cycle gas engine

Knoking



Metan slip

Low NO_X

Image source:
http://power.cummins.com/sites/default/files/literature/technicalpapers/PT-7009-LeanBurn-en.pdf

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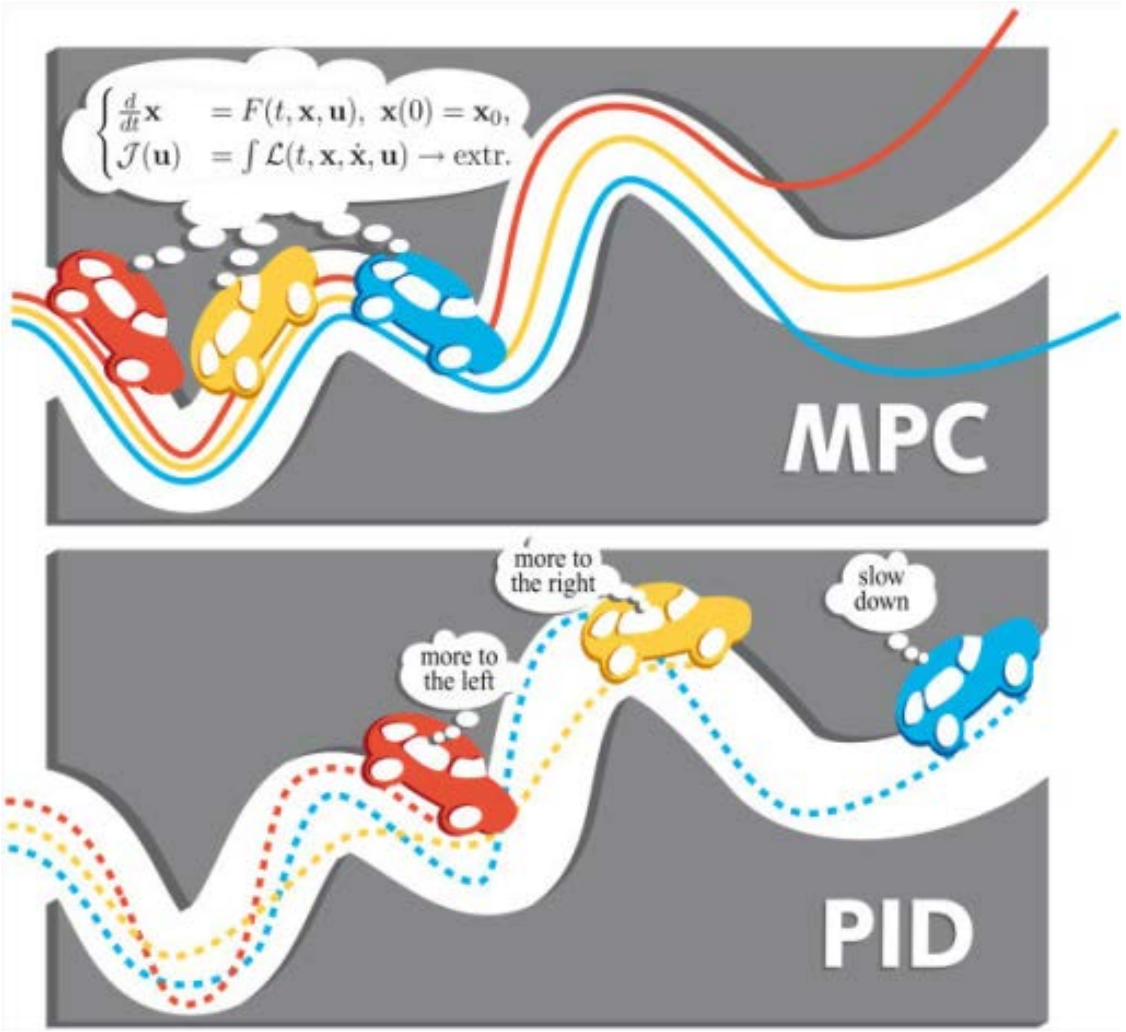
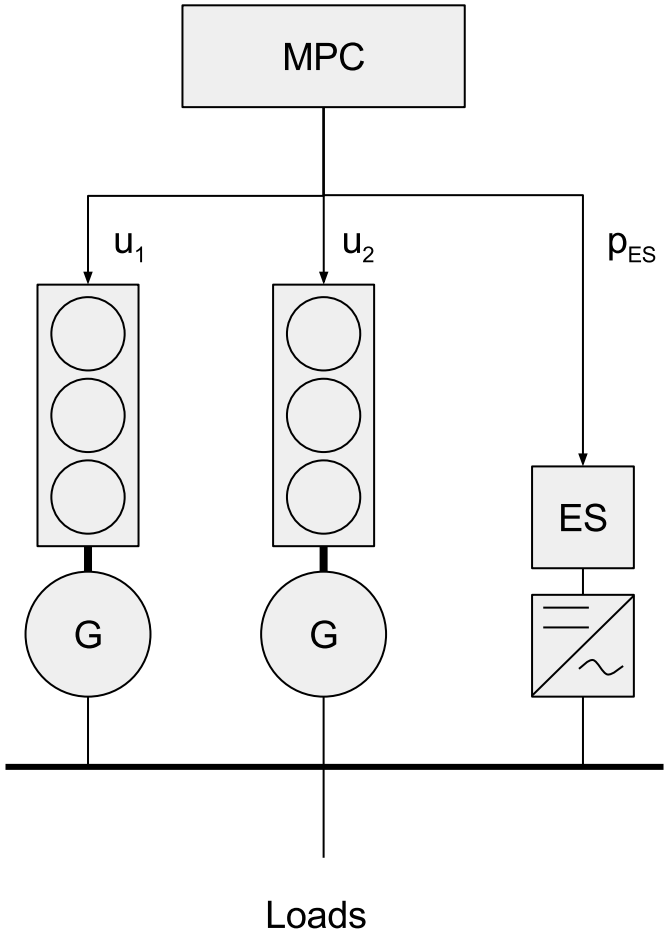

$\begin{cases} \frac{d}{dt}\mathbf{x} &= F(t, \mathbf{x}, \mathbf{u}), \ \mathbf{x}(0) = \mathbf{x}_0, \\ \mathcal{J}(\mathbf{u}) &= \int \mathcal{L}(t, \mathbf{x}, \dot{\mathbf{x}}, \mathbf{u}) \to \text{extr.} \end{cases}$
MPC
more to the right
slow down
more to the left
PID

Case

Two gas engines
2.2 MW
Maximum rate of change 0.5%/s
Energy storage (battery)
260 kWh, 780 kW, ~3800kg
Given load series



Results: removed from presentation

Conclusions

Mode	Cycles after 10 years	RMS $\dot{u}$ [%/s]
Frequency barrier, baseline	18,432	0.77
Frequency barrier, MPC	10,920	0.28
Stiff frequency, baseline	38,805	30
Stiff frequency, MPC	29,136	0.32

Questions?